PB-234 931

SOLID WASTE MILLING AND DISPOSAL ON LAND WITHOUT COVER

VOLUME II. DATA CONDENSATIONS

CITY OF MADISON, WISCONSIN

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

1974

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BIBLIOGRAPHIC DATA SHEET

1. Report No. EPA/530/SW62d.2

2.

PB 234 931

4. Title and Subtitle
SOLID WASTE MILLING AND DISPOSAL ON LAND WITHOUT COVER
Volume II

5. Report Date
1973

6.

7. Author(s)
John J. Reinhardt and Robert K. Ham

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
City of Madison, Wisconsin

10. Project/Task/Work Unit No.

11. Contract/Grant No.
G06-EC-00004

12. Sponsoring Organization Name and Address
U.S. Environmental Protection Agency
Office of Solid Waste Management Programs
Washington, D. C. 20460

13. Type of Report & Period Covered
Final 1966-1972

14.

15. Supplementary Notes

16. Abstracts

The project began as a practical demonstration to investigate the concept of milling solid waste for landfill disposal without applying daily cover. The project was intended to gather data on the operation and cost of milling equipment, the use of milled solid waste in a landfill, and the characteristics of milled solid waste--all from a practical standpoint. Eventually, however, project personnel carried out detailed investigative work on both milled and unprocessed solid waste. To determine whether landfilling milled solid waste lived up to the approval given by European landfill operators, it became necessary to design experiments involving rats, flies, leachate, gas, trees, etc. in hopes of quantifying such factors. Volume II contains condensations of data gathered during the project and has been arranged in sub-reports intended for the researcher who may wish to review the data.

17. Key Words and Document Analysis. 17a. Descriptors

*Waste disposal, Urban areas; Crushers, Comminution, Grinding mills

17b. Identifiers/Open-Ended Terms

*Solid waste disposal, Madison, Wisconsin

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NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. COSATI Field/Group

18. Availability Statement
Release to public

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
462

22. Price
$9.25

i

SOLID WASTE MILLING AND DISPOSAL ON LAND WITHOUT COVER

Volume II: Data Condensations

This final report (SW-62d.2) on work performed
under Federal solid waste management demonstration grant No. G06-EC-00004
to the City of Madison, Wisconsin, was written
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An environmental protection publication (SW-62d.2) in the solid waste management series

238108

MADISON'S MILLED REFUSE PROJECT

VOLUME II

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I INTRODUCTION

I-A - Background

This volume contains reports of the major research efforts undertaken during a project in Madison, Wisconsin, to demonstrate the feasibility of milling refuse for landfilling without daily cover. The demonstration project was conducted between 1966 and 1972 under grants from the Department of Health, Education, and Welfare and the Environment Protection Agency.

The chapters in this volume are meant to provide a detailed account of individual research projects. This volume, therefore, should be especially useful to engineers and others who need to review the data used in reaching the conclusions which form the basis of volume I of this report.

The project began as a practical demonstration to investigate the concept of milling refuse for landfill disposal without daily cover. It was intended to gather data on the operation and cost of refuse milling equipment, the use of milled refuse in landfill, and the characteristics of milled refuse--all from a practical standpoint. Project personnel ended up doing extensive research work, on both milled and unprocessed refuse, which was far removed from the idea of a demonstration project. The major reason for the vast amount of research involved in this demonstration project was the need to show numerically that milled refuse without daily cover lives up to the glowing praise offered by European landfill operators. As a result, it was necessary to design experiments involving rats, flies, leachate, gas, trees, etc., which hopefully would quantify such factors. While some crude techniques for making measurements on these parameters existed in the solid waste field, only a few suggestions could be gleaned from the literature or from similar projects. It was therefore necessary to pioneer in such areas as to how to measure particle sizes of refuse and how to compare the occurrence of flies on a sanitary landfill face and the surrounding area with their occurrence on a milled refuse disposal site.

In drawing conclusions and developing a report, the investigators in this project used not only the numerical data but also seven years of field experience and observations to present the story. It should also be kept in mind that there is a difference between the idealized, textbook views of the environmental aspects of a covered unprocessed landfill and what occurs in the field during years of operation. Thus, comparisons between milled and unprocessed refuse must be based on actual day-to-day field operations and not on theoretical considerations.

Milling was begun in Europe to provide material suitable for composting. The original single- or double-rotor hammer mills were designed to handle homogeneous materials; thus ungrindable items had to be manually sorted and removed.

A French manufacturer of grain-grinding machines made the crucial observation that led to the capability of milling heterogeneous material such as refuse. He was trying to learn why his grain mill was unable to grind high-moisture corn, and during an investigation of this problem he had a portion of the cover on the machine cut out. He observed that dry grain particles were readily ground. The softer, spongier, moister grains, however, remained unground and were accelerated through the opening in the top of the machine. The manufacturer of grain grinders thus learned that nongrindable objects can be ballistically separated from grindable objects in a mill. The ballistic rejection feature of the mill was awarded U.S. patent 3,082,963 on March 26, 1963.

The idea of ballistically separating nonmillable refuse through a "chimney" above a hammermill was developed into a test machine which was installed in Meaux, France in the early 1950's. Since there was no composting plant in the vicinity, the milled refuse was simply deposited on land near the machine. Amazingly, the milled refuse did not create a nuisance.

The original mill at Meaux was fed by hand at the inlet opening. It soon became apparent that a mechanical feeding mechanism would be needed to maximize the machine's output. Development of mechanical feeding machinery took another two years, however.

By 1970 there were over 50 installations employing this feeding and milling equipment in western Europe (Figure 1). Almost all landfilled the milled refuse without daily cover.

By the mid-1960-s, the first Gondard plant was in operation in North America -- at Montreal, Canada. In this plant, two Gondard mills are used in a parallel arrangement for refuse milling by a commercial salvaging company. About 25 percent of the tonnage brought to the mill during its first years of operation was salvaged and sold. The major item salvaged was paper. The remainder of the milled refuse was dumped along with unprocessed refuse in an uncontrolled fashion; thus it was difficult to draw conclusions about many aspects of landfilling milled refuse from the Montreal operation.

European experience, however, has indicated that handling milled refuse at a landfill site is simple and convenient. It is merely dumped and graded as desired. Since milled refuse is relatively uniform in size and composition, compaction and settlement are even. The material provides excellent support for rubber-tread vehicles, and since glass objects are reduced to tiny pieces, damage to tires of landfill machinery is greatly reduced. The nuisance caused by blowing paper and dust produced by packing machinery is greatly reduced. The danger of fire in the landfill is greatly lessened. Many vectors, especially rates and flies, are reduced in numbers or eliminated from the landfill. Milled refuse is esthetically more pleasing than unprocessed refuse and therefore is more readily accepted by the public. Finally, according to European claims, milled refuse that has been landfilled does not require daily covering.

Figure 1. Installation of Four Gondard Mills at Wiesbaden , Germany, 1966

The Heil Company of Milwaukee, Wisconsin, manufacturers and marketers of truck bodies for solid waste collection, learned of the Gondard milling process through sales activities in France, Switzerland, Netherlands, and Germany. Company representatives were impressed by the European claims of the attractive features of milled refuse and thus set out to find a city in the United States to undertake a test project involving refuse milling.

An incentive to potential users of the new milling system was the Solid Wastes Act of 1965 which provided matching funds for projects which would demonstrate on a production scale new methods of managing solid waste. Efforts to interest a community in Milwaukee County in trying the new system proved unsuccessful when it appeared that the project would interfere with development of a county-wide incineration system.

Continuing their search, the Heil representatives contacted Professor Gerard Rohlich of the University of Wisconsin-Madison College of Engineering. Professor Rohlich felt that the system warranted investigation and encouraged Madison's Director of Public Works, City Engineer, and Superintendent of Streets and Sanitation to investigate the possibilities and to view the Montreal operation.

An inspection trip to the Montreal facility took place in February 1966, following a prolonged thaw. The haul roads into the landfill site were almost impassable to automobiles. However, the traffic-bearing quality of the uncovered milled refuse in the landfill was remarkable. The visitors were able to walk on the refuse surface without overshoes, and loaded trucks sank only three or four inches into the material.

The ease of operation at the Montreal landfill, even under adverse conditions, convinced the Madison officials to recommend to the Madison Common Council that they be permitted to apply for a grant to fund a demonstration project. The proposed project would investigate European claims that milled refuse can be landfilled without daily cover as well as determine what modifications would be necessary to adapt the system to refuse generated in this country. The cost of such a system would also be carefully documented, and the characteristics of milled refuse would be studied.

In April 1966, the Common Council approved the submittal of a proposal to the Department of Health, Education, and Welfare and designated the Olin Avenue landfill site as the location of a proposed plant.

The City of Madison received a three-and-one-half-year grant, number 5-D01-UI-00004, from HEW in June 1966. The grant was renewed and expended several times to cover additional work.

The general objectives of the demonstration project have been:

1. To evaluate operation and economics of the Gondard and Tollemache mills, the associated conveyors, the final disposal system, and the milling plant.

2. To investigate the properties of milled refuse itself.

3. To verify or disprove European claims that milled refuse can be used in landfills without daily cover.

The participants in this milled refuse project included: 1) the City of Madison, which provided the plant site, site improvements, operating personnel, matching funds, and, of course, the refuse; 2) the Heil Company of Milwaukee, which furnished and installed the equipment and provided matching funds; under terms of a purchase option contract, Madison bought the equipment in 1969 after it proved successful; 3) the University of Wisconsin-Madison, which collected data and evaluated the project.

I-B - Acknowledgements

The persons who initiated the refuse reduction project in Madison included Arnold Meyer, Vice President of the Heil Company; Gerard Rohlich, Professor of Civil Engineering, University of Wisconsin-Madison; Edwin Duszynski, Director of Public Works, City of Madison; John Thompson, former City Engineer, City of Madison; and James Brophy, Superintendent of Streets, City of Madison.

Overall responsibility for the project has been in the hands of John J. Reinhardt, Principal Civil Engineer, City of Madison; and Robert K. Ham, Associate Professor of Civil and Environmental Engineering, University of Wisconsin-Madison. Evaluations were carried out under direct supervision of Warren K. Porter and Gerald W. Sevick, Project Specialists.

The project has had several Environmental Protection Agency project officers of which the primary ones were David Arella and Roger Graham.

Major investigations were conducted by Charles R. Anderson, Larry Hendrickson, James R. Boyle, Rameschandra Gawalpanchi, Everett W. Clodfelter, Fred Courtsal, Gier Wigdel, Vincent Geier, Walter L. Gojmerac, and Daniel M. Benjamin.

Assisting in the project have been Gary Boley, Robert Karnauskas, Kenneth Brunner, Herbert Hanneman, David Potwin, Richard Presney, Ellsworth Fisher, Earl Ulsrud, Charles Maas, Raymond Dillabough, Warren Kimberley, Richard Steinhofer, William Martin, Mary Smits, Eugene Davenport, and Al Kelly.

Student assistants have included Wendy Arndt, Douglas Lindquist, William Merry, Robert Schmidlen, and Daniel W. Benjamin.

Production of the final report for this project has been the responsibility of John Wolf and Austin Henry.

Special recognition is given to Doris Habich for typing and retyping the project's numerous reports over the past six years.

I-C - Definitions

Several terms used throughout this volume require short definitions. Most of the definitions are adapted from APWA Municipal Refuse Disposal, Chicago, (1970), and the EPA Publication Solid Waste Management Glossary (SW-108ts), 1972.

1) Refuse (also called solid waste). Useless, unwanted, or discarded material. This report is concerned primarily with residential (also called domestic) and light commercial refuse -- that is, all solid waste that normally originates in a residential environment. Industrial, institutional, and large quantities of commercial refuse are generally collected by private firms in Madison and are not normally milled.Large tree cuttings, bulky items, and construction-demolition debris are also handled separately at Madison.

2) Garbage (also called food waste). Animal and vegetable waste resulting from handling, storage, sale, preparation, cooking, and serving of foods.

3) Rubbish. A general term for solid waste -- excluding garbage and ashes -- taken from residences, commercial establishments, and institutions.

4) Milled Refuse. Refuse that has been mechanically ground, shredded or pulverized.

5) Unprocessed Refuse. To avoid confusion, this term will be applied uniformly to unmilled, crude, or raw refuse.

6) Cell. A volume of compacted solid waste which may be enclosed by natural soil or cover material in a sanitary landfill, not covered as in the case of test volumes of milled refuse, or enclosed in concrete beds in other test situations.

7) Sanitary Landfill. A method of disposing of solid waste on land by utilizing sound engineering and planning principles, by spreading the waste in layers, compacting it to the least practical volume, and covering it with soil at the end of each working day.

8) Bulky Items. Madison routinely collects large, bulky items such as furniture, tires, and matresses separately. Such material is not milled but landfilled separately.

9) Rejects. These are items which the mills ballistically separate because they cannot be pulverized to the desired particle size.

10) Cover. Soil which is placed over material in a sanitary landfill at specified intervals, usually daily.

11) Vector. An organism that is capable of transmitting a pathogen.

12) Leachate. Liquid that has percolated through solid waste and has extracted, suspended, or dissolved material from it.

13) Actual Refuse Density. The figure derived by dividing the weight of a portion of refuse by the volume of that refuse.

14) Effective Refuse Density. The figure derived by dividing the weight of a load of refuse by the volume of landfill space it takes up (including any cover).

15) Operational Production Rate. Tons processed during the time in which a mill is actually running. Down time is omitted from this figure, Thus, it is a measure of a mill's efficiency.

16) Down Time. In evaluations of the mills separately, time when a mill was shut down due to mechanical problems. In evaluations of the two-mill operation, all times during which the mills were not grinding refuse, between the initial start-up of the mill to the shut down at completion of the production day (e.g., any time the mill is not running during normal working hours).

17) Overall Production Rate. Tons of refuse processed divided by time during which the mill(2S) was grinding, plus down time. Thus, it is a measure of the plant's efficiency.

18) Millfilling. An engineering method of disposing of solid waste on land without daily cover by milling the waste, spreading it in layers and compacting it to the smallest volume practical.

II CONCLUSIONS

Among the conclusions of the demonstration milling project in Madison between 1966 and 1972 are the following:

1. As operated at Madison, the Gondard hammermill has a capacity of 9 tons per hour with a 5-inch grate, and the Tollemache hammermill has a capacity of 14 tons per hour with a 34-hammer pattern. The grate size and hammer pattern were chosen to grind refuse as coarsely as possible without producing problems of blowing litter at the landfill. (On a dry-weight basis, between 80 and 90 percent of the particles produced by both mills pass through a 20 inch screen). Evaluations of the two mills separately showed that the Gondard mill uses nearly as much electrical energy as Tollemache mill while producing only about 60 percent as much milled produce as the Tollemache.

2. Aside from some minor problems with the mills themselves, most of the early operational problems were associated with conveying refuse to the mills and carrying milled refuse to the landfill. The steeply inclined feed conveyor and the stationary compactor with a 75-cu.-yd. transfer vehicle used with the Tollemache mill have greatly increased the ability of the Madison plant to handle unprocessed and milled refuse on a production basis.

3. Residential and light commercial refuse as collected at Madison can be milled in either type of hammermill without presorting and with negligible downtime due to mill stoppage.

4. Milled refuse has been left in a landfill without cover for up to 6 years, and no complaints have been received about odors, unsightliness, blowing litter, rodents, or insects. Public acceptance of the milling plant and the landfill has been unusually good.

5. Experience with milled refuse without daily cover indicates that the quality of operation at this type of landfill is superior to sanitary landfill operations at Madison with respect to travel over the fill and at the face of the fill, dust, tracking of trucks on highways, appearance during operating hours and maintaining a uniformly high level of operation during cold and wet weather. Fully loaded trucks weighing nearly 73,000 lbs. can drive on milled refuse in inclement weather. Also, tire problems have not been caused by travel on uncovered milled refuse.

6. Experience and specific testing have shown that there is less of fire hazard with milled than with unprocessed refuse.

7. Rats are not able to survive on properly milled refuse containing up to 20 percent wet garbage on a wet weight basis. Based on this finding and on observations of the landfill site, there is very little likelihood of rat infestation and survival in a milled refuse landfill.

8. Under optimum weather and moisture conditions, flies probably can breed in freshly milled refuse; however, once such refuse has aged several months, this ability is evidently lost. Tests with the Gondard mill showed that a very large percentage of fly maggots passing through the mill during normal operation were killed. Fly counts and operating experience at Madison indicate that there is no fly nuisance problem associated with milled refuse.

9. Compaction of cover soil, as well as production of methane and carbon dioxide by underlying refuse, created poor aeration conditions for tree roots and thus led to a high mortality of trees planted on milled and unprocessed refuse cells after 2 years. White ash and crab were the most successful of the tree varieties planted in that they developed effective lateral root systems in the densely compacted cover soil.

10. Actual refuse density of milled refuse on a wet-weight basis was found to be approximately 27 percent greater than the actual refuse density of unprocessed refuse given equal compaction. Under the same conditions, the effective refuse density of milled refuse was calculated to be nearly 35 percent greater than that of unprocessed refuse.

11. Leachate production occurs at a faster rate in milled uncovered cells than in covered cells, milled or unprocessed. In the absence of cover, milled refuse develops a relatively mature degradation pattern and thus lowers the organic pollution load leaving the refuse in leachate. Before a mature degradation condition develops in milled refuse, large quantities of organics in particular are leached from milled refuse.

12. The covered unprocessed refuse cells never produced organics at as high a rate as did the milled cells during initial stages of decomposition; however, the unprocessed cells continued to produce organics at a fairly consistent rate throughout the duration of the project. Thus, the milled refuse cells could be characterized as producing more leachate contaminants during initial stages of decomposition but less during later stages of decompostiion than the unprocessed refuse cells.

13. A water budget analysis shows that in Madison, Wisconsin, about 68 percent of incident precipitation on covered refuse in a landfill evaporates, while the remaining 32 percent is divided almost equally between runoff and infiltration (leachate). Virtually no runoff and slightly more evaporation occurs with uncovered milled refuse.

14. In the first evaluation of the Gondard mill with a 5-inch grate in mid-1968, a per-ton cost of $7.75 - including process and hauling costs but excluding landfilling costs - was experienced. When this figure was adjusted to exclude factors related solely to the experimental aspects of the operation, a comparable cost of $5.33 per ton emerged as a reasonable estimate for a production facility. During an evaluation of the Tollemache mill in the summer and fall of 1970, a cost of $4.74 per ton for milling and hauling (but not landfilling) was calculated. A winter evaluation early in 1971 yielded a cost per ton of $5.71. These two Tollemache figures are based on the weight of refuse as received at the plant and include increased labor costs incurred during the second evaluation.

15. For a two-mill, two-shift operation during the first 6 months of 1972, a milling cost of $3.90 per ton was determined, based on 23,317 tons milled; another $0.48 per ton must be added to this figure to cover stationary compaction and hauling less than 1/2 mile. The operating costs of landfilling for the first 6 months of 1972 in Madison were $0.99 per ton for milled refuse and $3.00 per ton for unprocessed refuse, excluding any land and development costs. During this period, regular sanitary landfills in Madison handled about twice as much material as did the milled refuse landfill.

16. Based on the findings of this study, a cost of $2.75 per ton of milled refuse was projected for a two-shift, two-Tollemache-mill operation. This figure includes milling, hauling less than 1/2 mile, and landfilling and assumes a continuous supply of millable refuse. The City of Madison will continue milling refuse at the Olin Avenue Milling Plant. In the Summer of 1973, the Olin Avenue millfill operation will be completed. The City has recently acquired another landfill approximately nine miles from the milling plant. The milling plant will serve as a central processing and transfer station from which the milled refuse will be hauled to the new millfill facility.

III OPERATION AND ECONOMICS

III-A - Gondard Operation

DESCRIPTION

The Gondard hammermill installed at the Madison Refuse Reduction Plant in 1967 is equipped with the conventional number of 48 1-3/16 x 4 x 11 in. swinging hammers on four shafts. The 15-lb.hammers are driven at 1150 r.p.m. by a Louis Allis 150 hp motor. A chimney over the mill permits ballistic rejection of large, unmillable objects.

To keep costs low, it was decided to build as small a building as possible to house the Gondard mill. This resulted in a complex system of three feeding conveyors (Figure 2). The original motors for all three conveyors were variable speed Sterling motor reducers. These were controlled by a special unit that permitted the operator to vary the speed of the two rubber belt conveyors or the conveyor in the 75 cu. yd. feed bin. The control unit also contains a system to automatically stop all three conveyors when power input to the mill motor exceeds 125 percent of rated load for 5 consecutive seconds.

The original discharge conveyor was a conventional transfer conveyor suspended with a trolley that permitted swinging from one to the other of two 10 cu. yd portable load lugger bins.

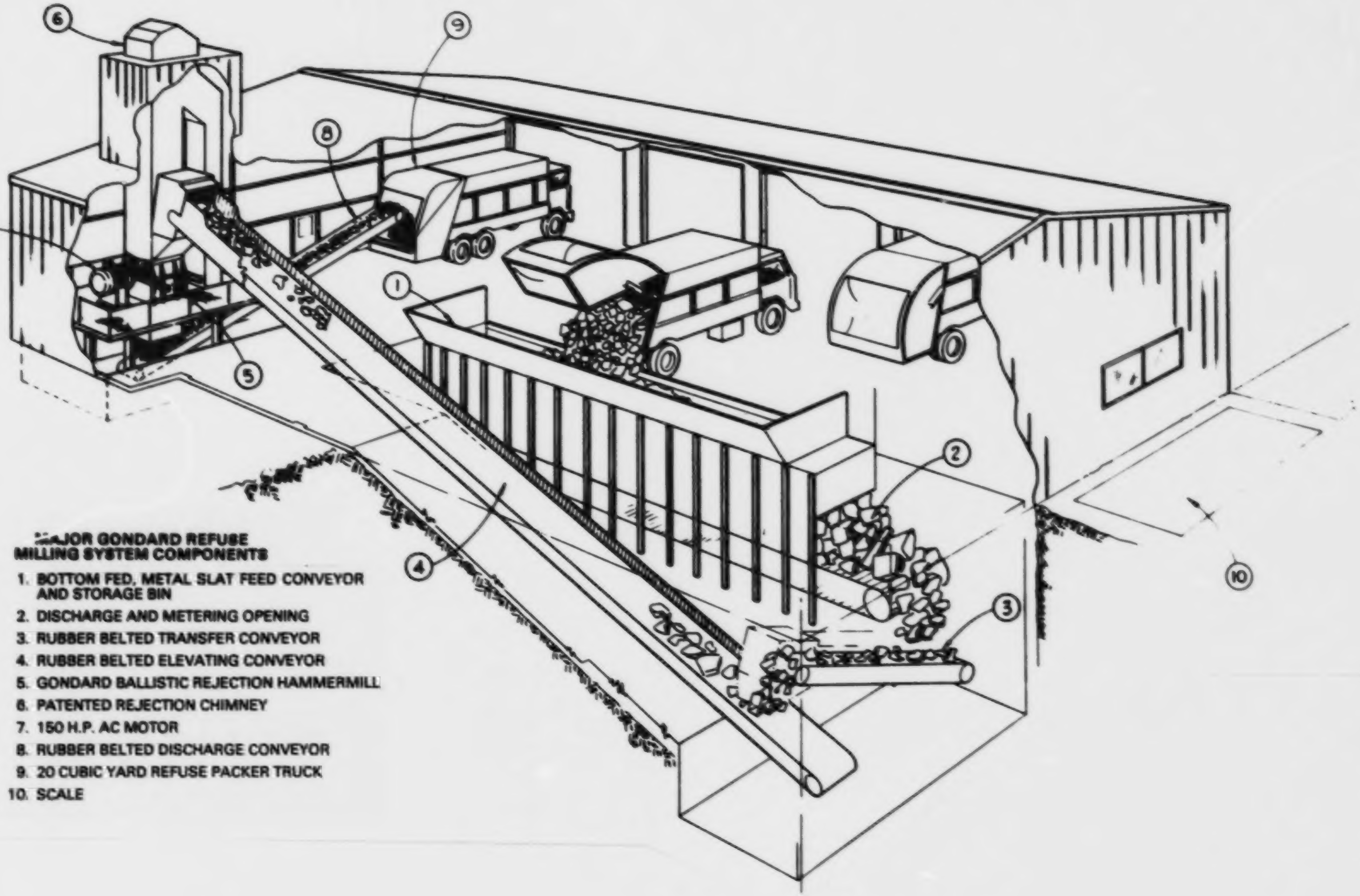
Figure 2 presents a perspective layout of the original plant as it was completed in the spring of 1967; it also serves as a flow diagram and indicates the machinery layout. Figure 3 is a side view of the mill and rejection tower. Figure 4 is an exploded view of the grinder itself, and Figures 5 and 6 show the exterior and interior, respectively of the original Madison Refuse Reduction Plant. Figure 7 is the Gondard mill with the housing open to show the horizontal rotor and the hammers.

PROBLEMS WITH ORIGINAL EQUIPMENT

The Gondard mill and conveyors were imported from France on the basis of satisfactory operations in Europe. Almost immediately, however, it became apparent that refuse generated in Madison was different from European refuse. For example, Madison's refuse contains more large items such as boxes. These differences, as well as mechanical problems, required modification of the Gondard system after installation at Madison.

Some of the modifications included:

1) Addition of 6-in.cleats to supplement the 3-in.cleats in the feed bin conveyor for handling the larger items in Madison's refuse;


6
9
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3
MAJOR GONDARD REFUSE MILLING SYSTEM COMPONENTS
1. BOTTOM FED, METAL SLAT FEED CONVEYOR AND STORAGE BIN
2. DISCHARGE AND METERING OPENING
3. RUBBER BELTED TRANSFER CONVEYOR
4. RUBBER BELTED ELEVATING CONVEYOR
5. GONDARD BALLISTIC REJECTION HAMMERMILL
6. PATENTED REJECTION CHIMNEY
7. 150 H.P. AC MOTOR
8. RUBBER BELTED DISCHARGE CONVEYOR
9. 20 CUBIC YARD REFUSE PACKER TRUCK
10. SCALE

Figure 2. Refuse Reduction Plant at Madison, Wisconsin, 1967

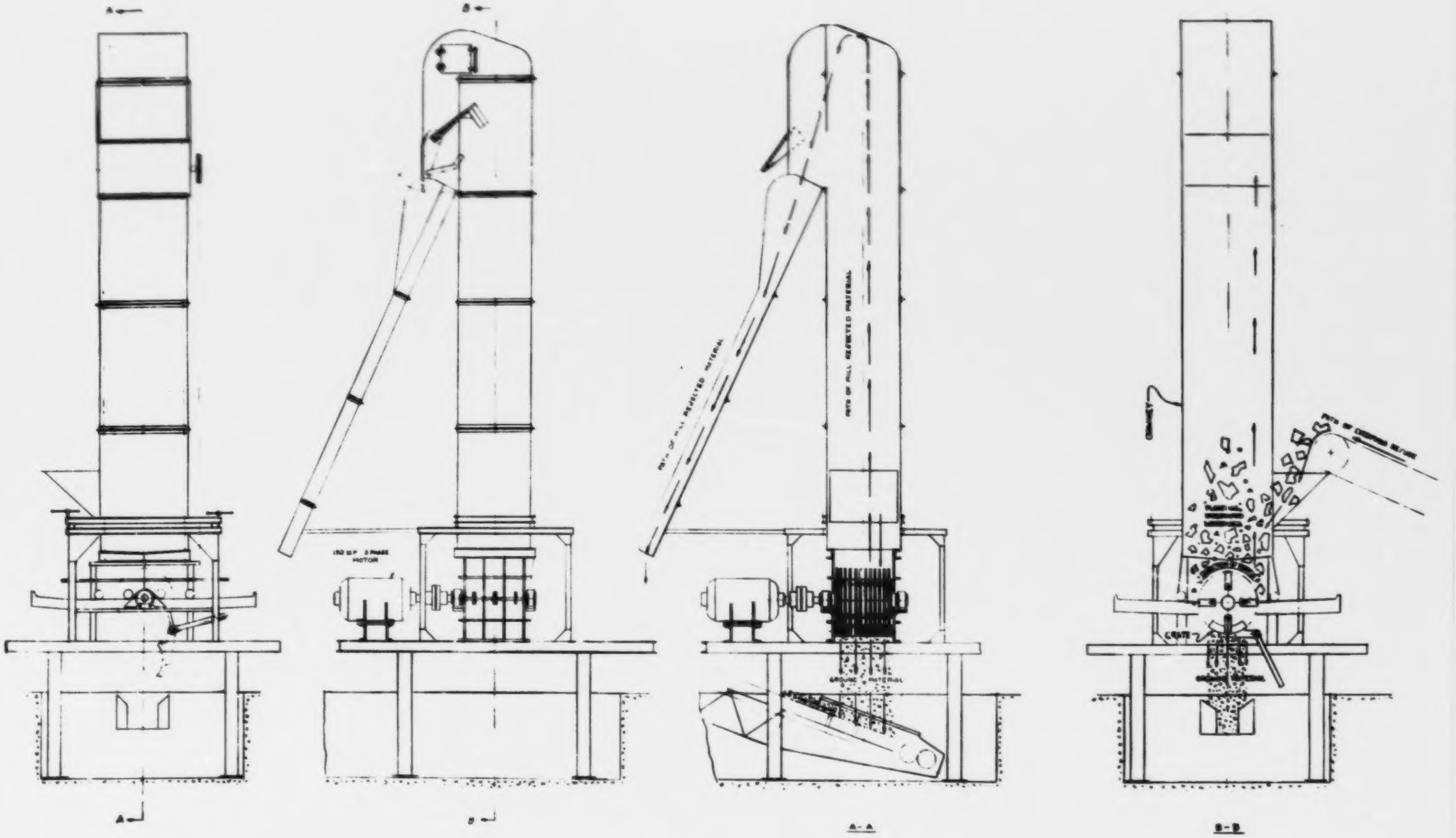
A
B
150 H.P. 3 PHASE MOTOR
PATH OF MILL REJECTED MATERIAL
PATH OF MILL REJECTED MATERIAL
GROUND MATERIAL
GRATE
A
B
A-A
B-B

Figure 3. Side Views of the Gondard Mill With Rejection Tower

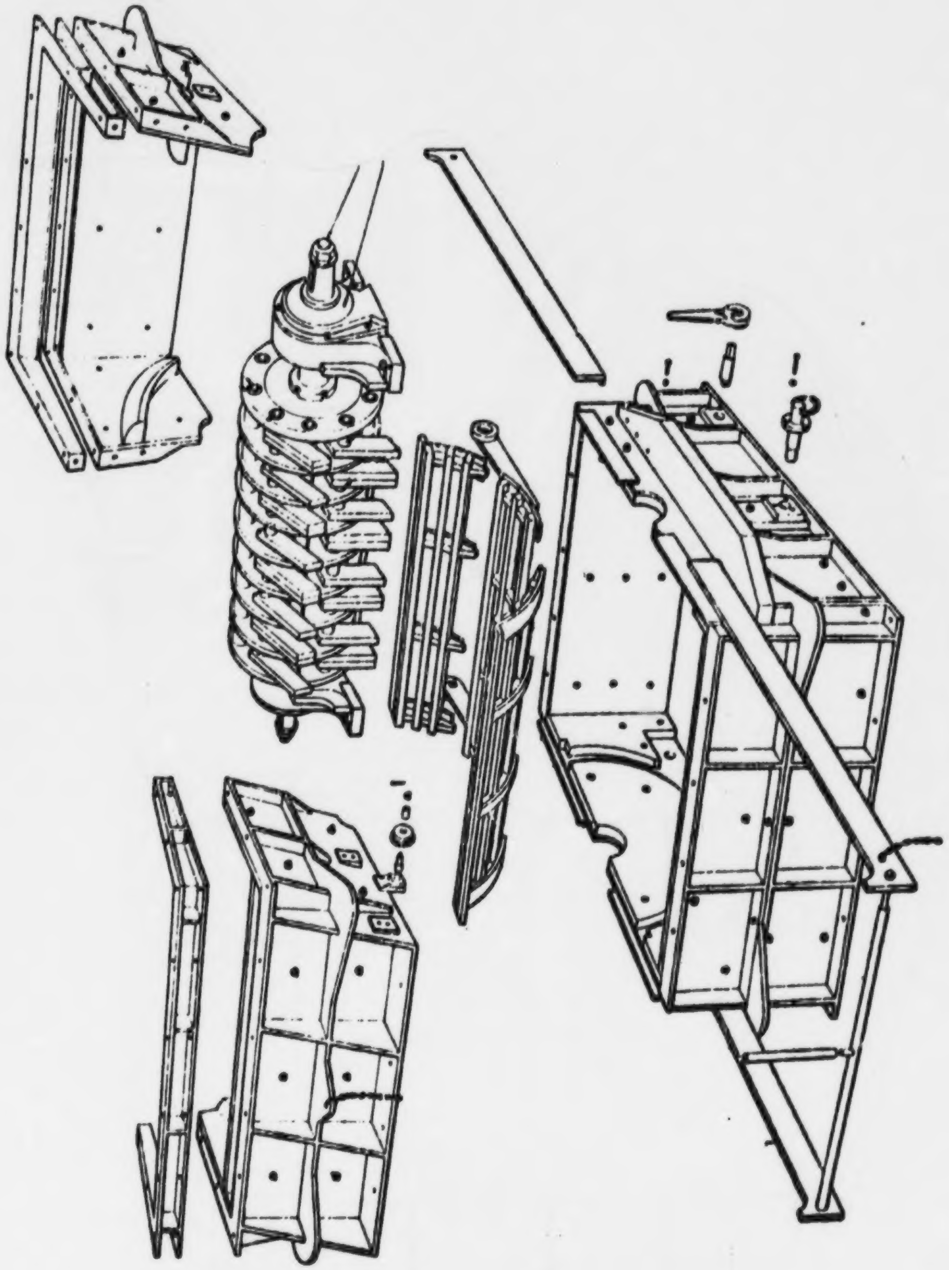

Figure 4. Gondard Mill, Exploded View

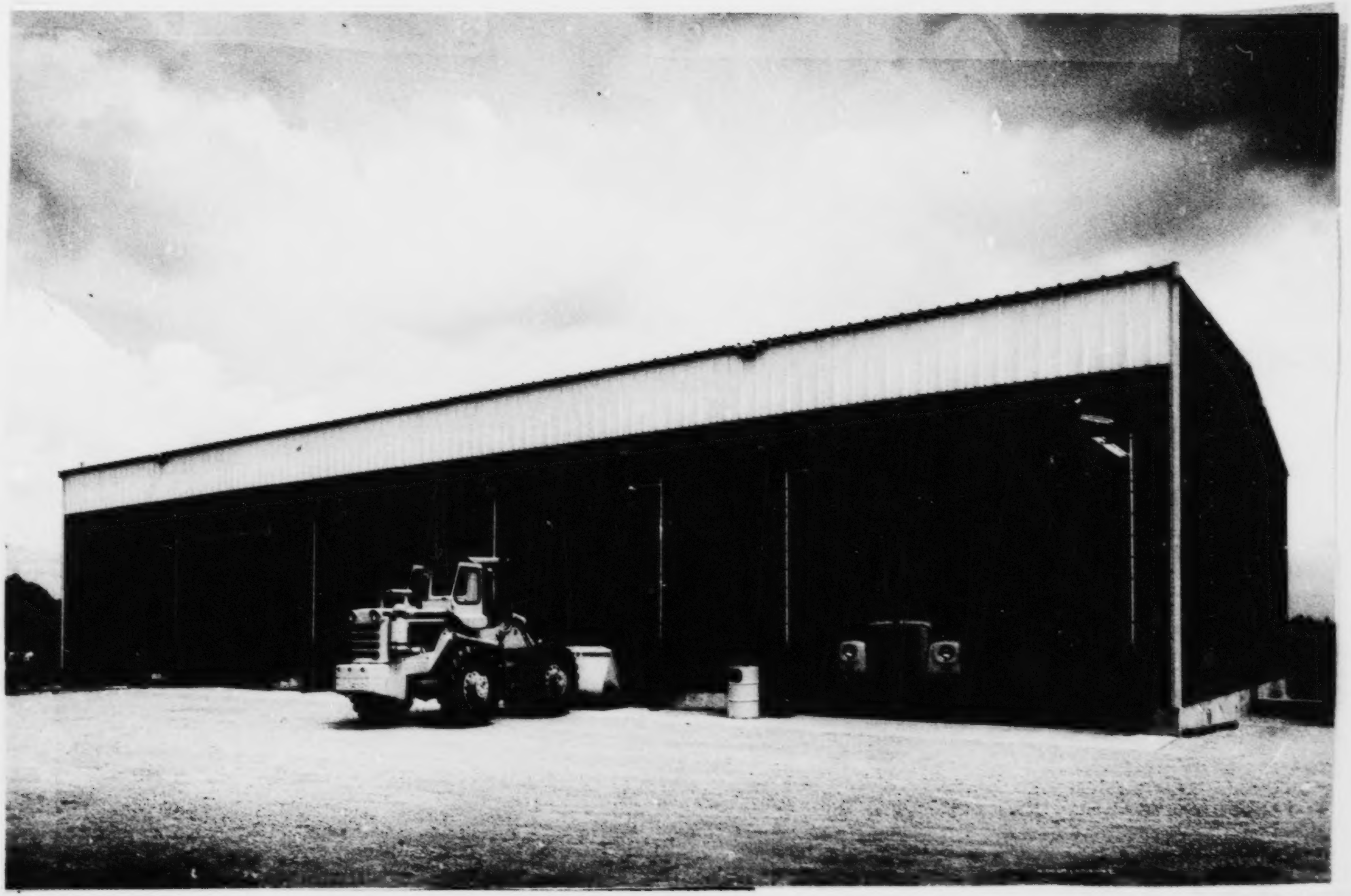

Figure 5. Refuse Reduction Plant Exterior at Madison, Wisconsin, 1967

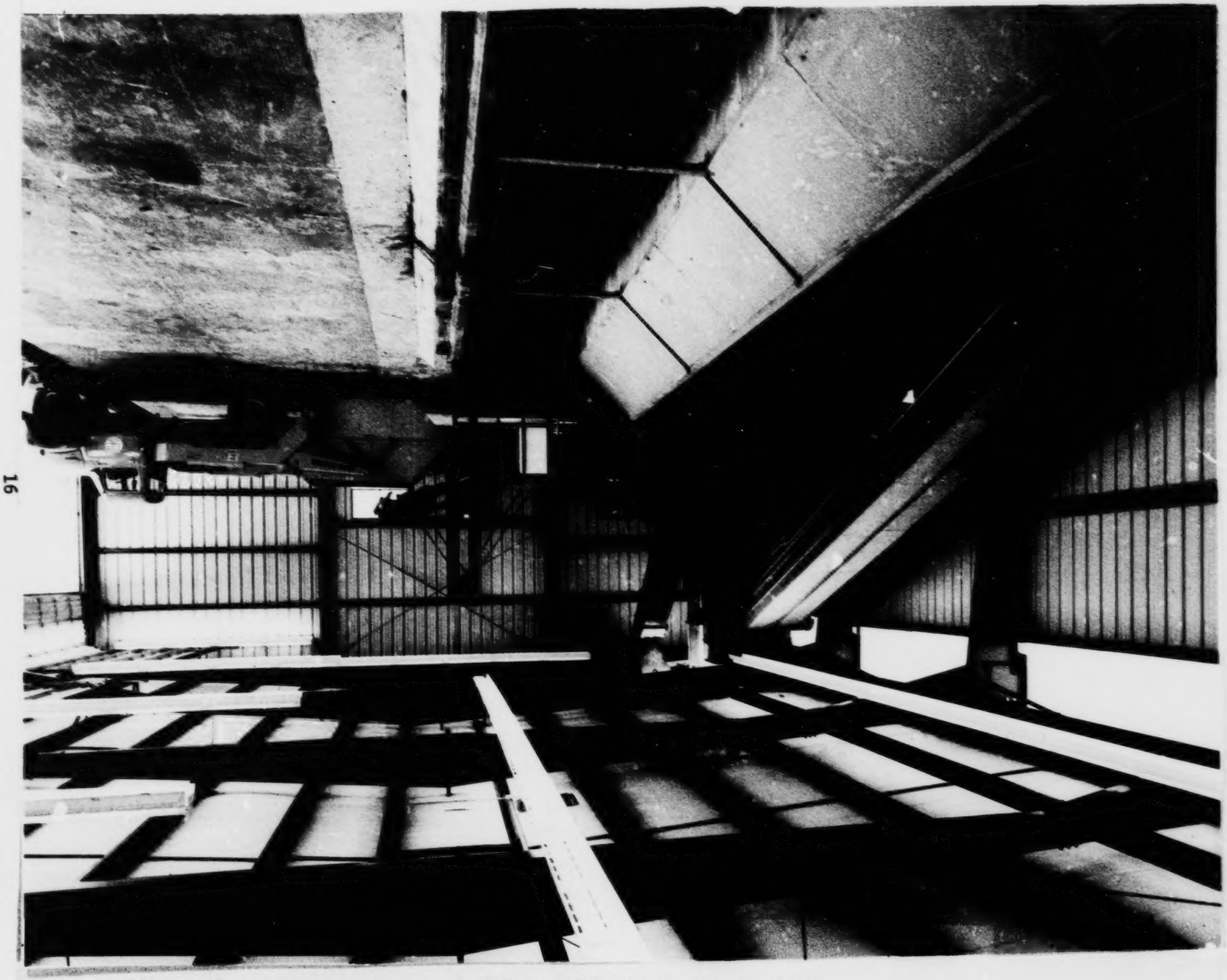

Figure 6. Interior View of Refuse Reduction Plant, 1967

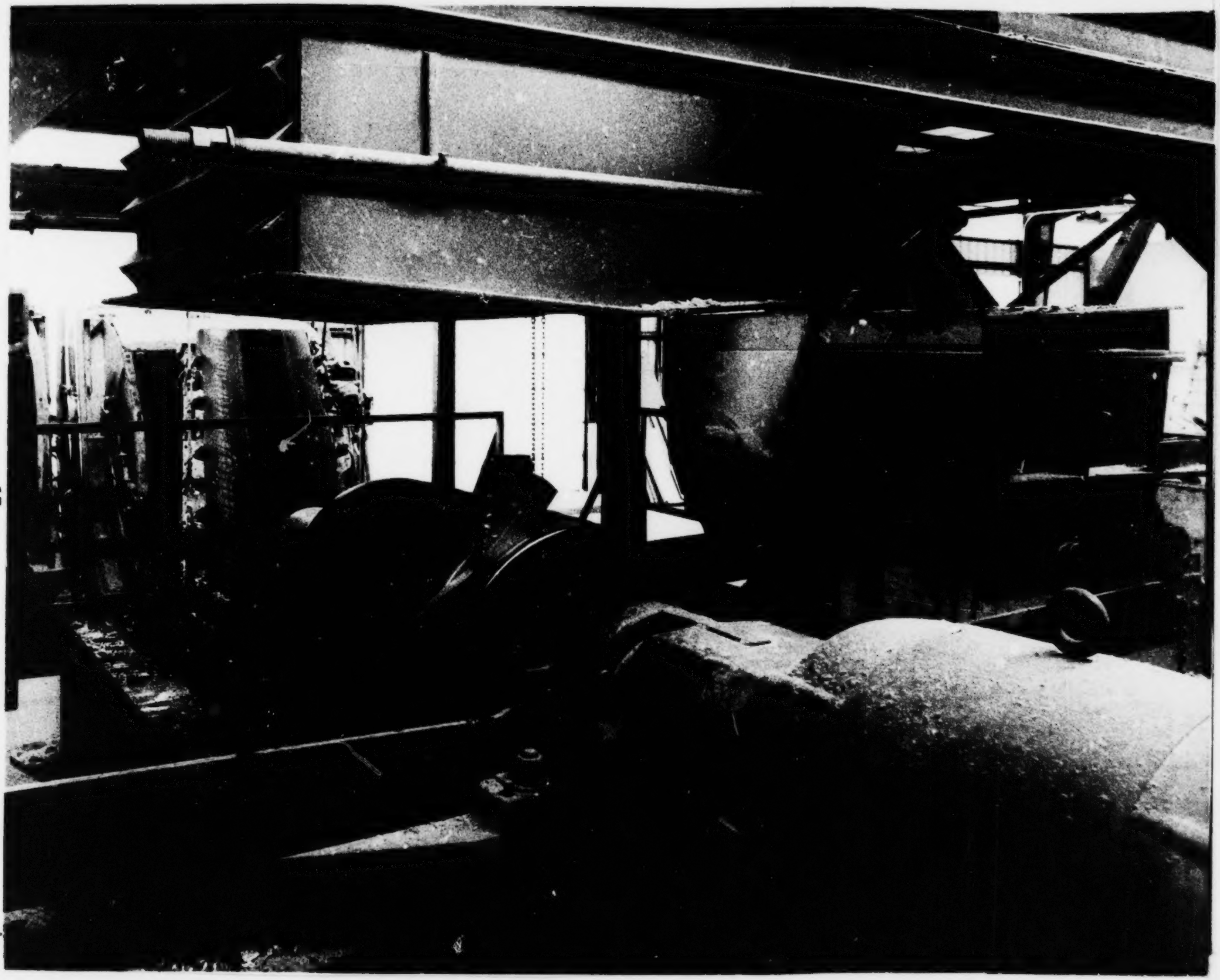

Figure 7. Gondard Mill at Madison, Wisconsin. Housing Opened to Show Horizontal Rotor and Hammers

2) Installation of spray bars around the area where the refuse leaves the bin conveyor and at the entrance to the mill to help reduce the dust problem;

3) Redesign of several components of the feed mechanism to prevent jams and improve uniformity of feed;

4) Revision of the servo motor on the bin feeder to allow rapid change of conveyor speeds.

The 10-cu.-yd. collection bins proved unsatisfactory when the milling system operated at 2/3 of capacity. This aspect is discussed further in the "Operation" portion of this section

MAINTENANCE

The hammers, of course, are subject to the greatest abrasion in this system. The rods on which the hammers swing require replacement about four times per year when operating on a one-shift basis; the spacers between the rotor disks have a similar lifespan. Other erodable elements are the grates and the liner or wear plates. These are maintained by arcweld hard surfacing. The maintenance program, when properly executed, can be carried out daily during the one hour cleanup period. Only if grate or liner replacement is required should it be necessary to perform such work on overtime. The fact that all elements of the hammermill are relatively thick and can be welded in the downhand position makes it easy to train personnel for this work.

Experiments with "tipping" or "hardfacing" the hammers were begun in February 1968. Results of tipping medium hard steel (SAE 1060) hammers were extremely good. Tonnage of refuse milled with one set of hammers was nearly doubled. Attempts to tip harder steel (SAE 1090) hammers resulted frequent fractures. Heating these hammers before tipping improved the situation, but fractures still occurred.

Experience has shown that a set of SAE 1060 hammers, properly hardfaced, can mill over 1000 tons of refuse.

OPERATION

Incoming refuse (see Appendix N) is first weighed and then emptied inside the building, either in the storage bin or on the floor when the bin is full. A frontend loader is used to push refuse from the floor into the storage bin as needed. The combination of refuse storage in a bin and on the floor was chosen to eliminate the need for an overhead crane and operator and to minimize handling the refuse.

The original system transporting the refuse from mill to landfill was a load lugger detachable container system consisting of a flatbed truck with hydraulic arms to lift a 10 cu. yd. bin onto the bed. Three bins were provided initially. One bin was placed under the reject chute and could hold the items rejected during one or two days of milling. The other two containers were located at the end of the conveyor bringing refuse from the mill. The conveyor was mounted on a track so that it could be switched from one container to the other. When one container was filled, a man stationed at the truck leveled the load, switched the conveyor to the other container, took the full load to the landfill, and replaced the emptied container in its original location. By the time he returned, the second container was nearly full. This man was thus continually occupied in emptying containers. Because of the fluffy nature of the freshly milled refuse, these 10 cu. yd. containers held only 2,500 to 2,000 lbs.

A change was made to mechanical compaction trucks. From January through November, 1968, two old packer trucks were pressed into emergency service. A person was needed to actuate the packing mechanism every few minutes. Adding to the cost of this equipment were frequent repairs.

During 1968, two models of 20 cu. yd. packer trucks were tested. Neither was able to keep pace with the volume of refuse discharged from the mill.

The final collection and transportation system tried during the Gondard tests involved two prototypes of a 25 cu. yd. truck to be manufactured by the Heil Company. These trucks had a packing mechanism that could be continously cycled by mechanical means. This system reduced both manpower needs and the number of trips to the landfill.

PRODUCTION

During the year of experimental trials with the Gondard system, the grate at the bottom of the mill, through which the milled refuse is driven, was changed systematically to determine the optimum grate size. The grate size is the space between bars of the grate. Considerations in optimization included machine capacity, operating costs, landfill space required, and particle size. Initially, plans called for using 2, 3 1/2, 4, 5, and 6 1/4 in. grates; however, tests with the 2 in. grates were discontinued almost immediately because they yielded particles finer than required for landfill and were slowing production.

The optimum size for use in Madison was found to be 5 in. This yields the highest production, 9 tons per hour, at lowest costs without producing blowing paper problems in the landfill. The production rates for the 3 1/2 and 6 1/4 in. grates were 8.6 and 9.4 tons per day, respectively, during the tests.

Tables 1 and 2 show production rates at various seasons and with different grate sizes. Two production rates were calculated: one based on machine operating time alone and the other based on machine operating time plus down time. Thus, "operating" production rate is tonnage processed during the time the machine is actually running, while "overall" production rate is tonnage processed during mill operating time plus down time. Not included in the overall rate is time lost because the plant is out of refuse, because of truck breakdowns, or because of the time lapse from arrival of the first load and the start of milling operations. These factors are not included because they are not due to machinery limitations but due to limitations in the plant itself. Time lost because of these nonmachine problems does, however, have to be taken into account in final cost analysis.

Theoretical capacity was not reached, probably because of material handling problems associated with the heterogeneous nature of refuse. A load factor, or ratio of power consumed to theoretical power consumption. wsas computed as a rough indicator of how hard the machine worked compared to its theoretical capacity. The average load factor ranged from 0.6 to 0.7, depending upon the grate size used. This factor has not been used to calculate a theoretical machine capacity, as such is a rather tenous concept.

Early in the project the rejectable items were separated into a bin and weighed from September 1967 through January 1968. During this time, it was found that between 1 and 7 percent by weight of the total refuse could be ballistically separated when the reject chute extended 27 feet vertically above the mill.

Appendix C presents the production data from the Gondard experimental runs.

COST DATA

Cost data are presented in this section for the third year of this demonstration project, from June 1968 through May 1969. Although it is proper to report the costs incurred in the existing plant, one must be cautioned about adapting these costs to other installations because this is a pilot plant demonstration project whose operation is probably more expensive than that of future plants. One also needs to recognize the regional variations in labor, power costs, heating costs, and depreciation methods. Inflation during the years since this study was undertaken must also be considered. One is referred to the subsequent section on cost projections for a more accurate indication of what future plants might cost. These projections indicate costs per ton ranging from $4.96 for one mill operated one shift to $2.13 for four mills operated two shifts.

TABLE 1

Gondard Overall Production Rate Vs. Grate Size - Tons Per Hour
(Operating Plus Down Time)

Period	Grate Size (opening between bars)		
	3-1/2 Inches	5 Inches	6-1/4 Inches
Fall 1967	6.0		8.4
Winter 1967-68	6.8	-	7.0
Spring 1968	6.9	7.8	7.9
Summer 1968	7.7*	8.0	8.1
Fall 1968	-	7.6	-
Winter 1968-69	8.1*	6.8	-
Spring 1969	9.2*	-	-
Average - last full year	8.3	7.4	7.7
Projected Average - based on later modifications	8.4	9.0	9.4

* The opening between the bars was actually four inches.

TABLE 2

Gondard Operating Production Rate Vs. Grate Size - Tons Per Hour
(Operating Time Only)

Period	Grate Size (opening between bars)		
	3-1/2 Inches	5 Inches	6-1/4 Inches
Fall 1967	6.8	-	9.3
Winter 1967-68	7.0	-	7.3
Spring 1968	7.1	8.2	8.1
Summer 1968	8.0*	8.2	8.4
Fall 1968	-	7.9	-
Winter 1968-69	8.4*	7.2	-
Spring 1969	9.7*	-	-
Average - last full year	8.7	7.7	8.1
Projected Average - based on later modifications	8.8	9.3	9.7

* The opening between the bars was actually four inches.

Futhermore, the unit costs in Tables 3 and 4 are higher than would be the case for a larger and differently designed plant because:

1) Refuse is not conveyed to the mill as fast as the mill can grind;

2) A similar plant without extensive foundations and extra conveyors would be less costly;

would be less costly;

3) A plant having proper haulaway equipment might be operated by two men, thereby reducing labor costs;

4) Adaptations and improvements can still be made in haul away operations.

Land costs are not included because they are commonly omitted from other studies, and because this plant was built on an existing city site purchased many years ago.

The costs per ton are calculated by divinding annual cost by the projected annual tonnage. The annual tonnage is calculated by using the "overall" production rate, the average number of operating hours per day, and the number of operating weeks per year. (See Appendix B)

Table 3 lists the cost per ton for each expense category for three different size grates.

Table 4 lists the same cost items which are adjusted on the basis of more operating hours per day, and one less man. It is assumed in Table 4 that the plant might be operated by two instead of three men for 7 hours overall instead of the present 5.33 hours per day. These costs are not further reduced for improved plant design. The method used to compute the costs listed below are described in Appendix A.

It was felt that transportation costs for this portion of the project were unduly high and should not be used in projecting costs for future installations. Thus, "transportation" figure is not presented in Table 4, "Adjusted Cost Per Ton".

CRITIQUE OF PLANT OPERATIONS

Besides the down time attributable only to the milling operation (jams of feed conveyors and the mill), there were considerable periods of nonproductive work. In an attempt to quantify these nonproductive work times, the daily records from April 1 through November 29, 1968 were examined. The average number of minutes per day of nonproductive work are itemized as follows:

3

TABLE 3

Unadjusted Cost Data For Gondard Mill
(June 1968 Through May 1969)

Cost Item	Annual Cost		Grate Size	
		3-1/2 Inch	5 Inch	6-1/4 Inch
			Annual Tonnage	
		10,750	11,500	12,050
Labor	$39,800	$3.70	$3.46	$3.30
Amortization	$32,200	$2.99	$2.80	$2.67
Power	variable	.34	.30	.30
Lighting	$ 2,300	.21	.20	.19
Water	$ 200	.02	.02	.02
Gas-heat	$ 1,200	.11	.10	.10
Hammer wear**	$1,600-1,710	.16	.15	.14
Mill Maintenance**	$850-950	.08	.08	.08
Small Equipment	$ 800	.07	.07	.07
General Supplies	$ 1,100	.10	.10	.09
Front End Loader Operation	$ 500	.05	.04	.04
Transportation to Landfill*	$ 3,250	.30	.28	.27
Other	$ 1,700	.16	.15	.14
TOTAL		$8.29 ton	$7.75 ton	$7.41 ton

*Based on round trip of less than 1/2 mile.

**Annual cost range reflects actual costs of the three grate sizes.

Annual cost range reflects actual costs of the three grate sizes.

4

TABLE 4

Adjusted Cost Data For Gondard Mill
(June 1968 Through May 1969)

Cost Item	Annual Cost	Grate Size 3-1/2 Inch	5 Inch	6-1/4 Inch
		Annual Tonnage 14,100	15,100	15,800
Labor	$28,500	$2.02	$1.89	$1.80
Amortization	$32,100	$2.28	$2.13	$2.04
Power**	$4,400-4,100	.31	.28	.26
Lighting	$ 2,300	.16	.15	.15
Water	$ 200	.01	.01	.01
Gas-heat	$ 1,200	.09	.08	.08
Hammer Wear**	$2,220-2,280	.16	.15	.14
Mill Maintenance**	$1,100-1,250	.08	.08	.08
Small Equipment	$ 800	.06	.05	.05
General Supplies	$ 1,100	.08	.07	.07
Front End Loader Operation	$ 700	.05	.05	.04
Transportation to Landfill*	$ 3,250	.30	.28	.27
Other	$ 1,700	.12	.11	.11
TOTAL		$5.72 ton	$5.33 ton	$5.10 ton

*Based on round trip of less than 1/2 mile.

**Annual cost range reflects actual costs of the three grate sizes.

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1. Elapsed time between arrival of first load of refuse and start of milling	33 minutes
2. Conveyor and mill jams	13 minutes
3. Nonproductive time during milling:	
out of refuse	15 minutes
truck breakdown	12 minutes
lunch	19 minutes
other	4 minutes

During the same period, there were 37 recorded cases of hammer maintenance and 24 cases of general maintenance which account for some of the nonproductive work time listed above.

Besides the nonproductive work times that were a part of daily operation, there were also certain days that the plant was shut down. A detailed tabulation of the dates, reasons, and solutions for these shutdowns appears in Appendix F. Two things should be noted: (1) Many of the shutdowns could be eliminated through proper initial design (this is something that is gained only by experience and is the purpose of such a demonstration project); and (2) other shutdowns could be reduced or eliminated by rearranging work schedules.

III-B - Tollemache Operation

DESCRIPTION

The Tollemache system consists of three basic elements: the feed mechanism, the mill, and the takeaway mechanism for the ground product. Each has its own characteristics and each is equally important in the normal daily operation of the plant, for if one system fails the plant cannot function on a normal basis. Following is a detailed description of each portion of the system including description, operation and operating problems.

TOLLEMACHE ELEVATING CONVEYOR

The Tollemache mill is fed by an elevating metal flight conveyor (**Figure** 8). The one piece, 54-in.-wide, conveyor is driven by a 20 h.p. motor equipped with a speed reducing mechanism and overload switch. The horizontal portion of the conveyor is considered the refuse storage area and is nearly 18 ft. long (Figure 9). The elevated portion is about 30 ft. long and makes an angle of about 45° with the horizontal. The speed reducer or variable speed drive mechanism allows the operator to adjust the conveyor speed from a minimum of 8 ft./min. to a maximum of 12 ft./min. The automatic overload stops the feed conveyor when the mill motor draws power 25 percent above its rated capacity. The conveyor restarts itself automatically after the mill motor draws less than 80 percent of its rated capacity for a 5 second period.

The conveyor pit is 5 ft. deep and the walls range from 4.5 ft. at the bottom to 12 ft. at the top. At the point the conveyor leaves the horizontal, the walls abruptly change to 4.5 ft. in width; thus, a constriction is placed on refuse flow. This constriction halts the forward movement of the refuse mass and creates a tumbling or rolling action which in theory should create an even feed to the mill (Figure 10). An even feed is a necessity for optimizing mill production. Thus refuse feeding is one of the most important functions in the overall mill operation.

Feed Problems:

In essence the type of feed being experienced in any one day determines the production rate of the mill during that day. If the mill is to operate at its rated capacity, 15 tons/hr., 1 ton of refuse must be transported to it every 4 min. At the maximum speed of 10 ft./min. and assuming a refuse density of 350 lbs./cu. yd. with a refuse depth of 1 ft., it would take 3.5 min. to feed 1 ton to the mill. This example is theoretical because refuse does not feed consistently at a depth of 1 ft., nor is the density always 350 lbs./cu. yd. or greater; but it is evident that there is not much room for conveyor delays.

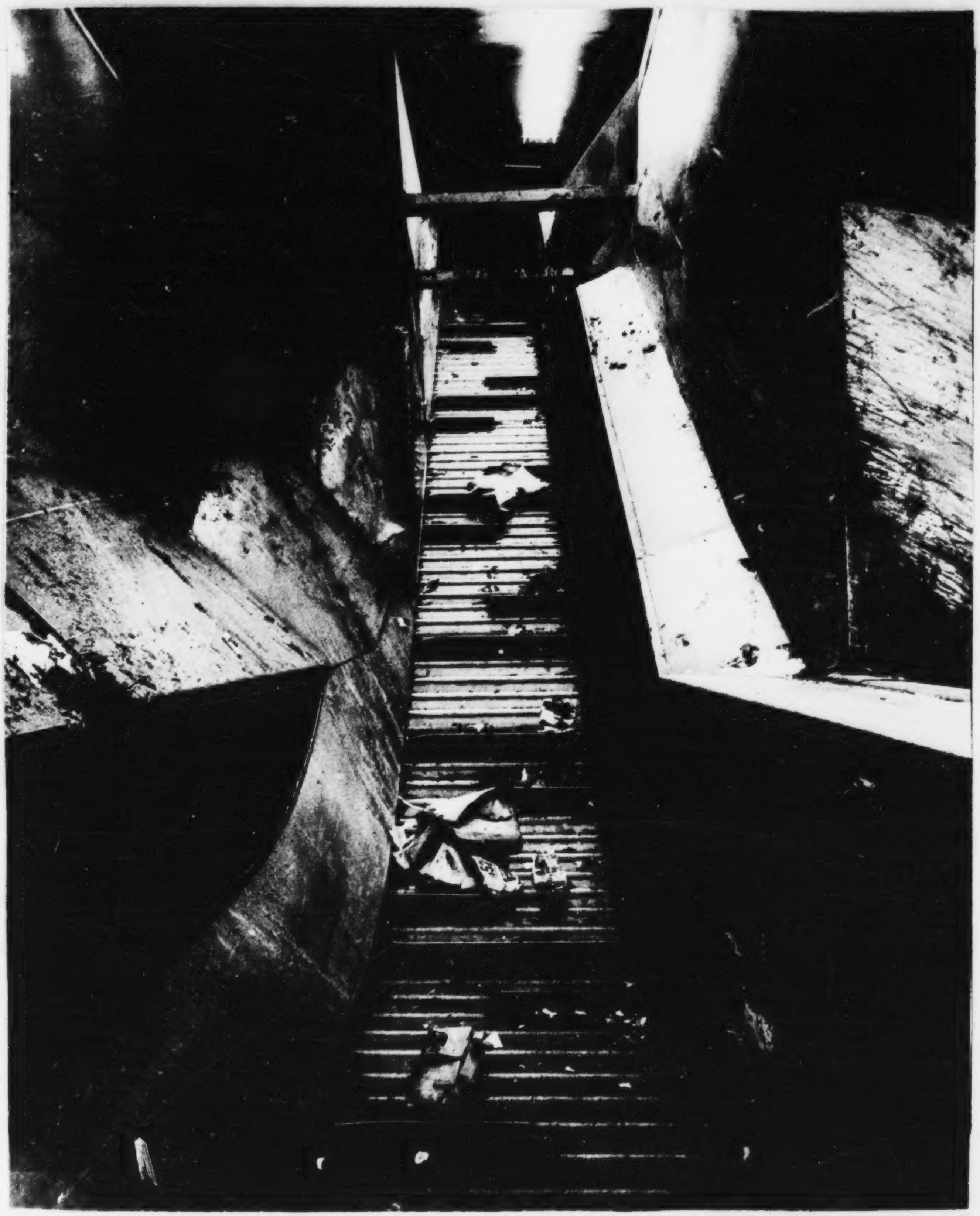


Figure 8. Tollemache Continuous Metal Belt Elevating Feed Conveyor

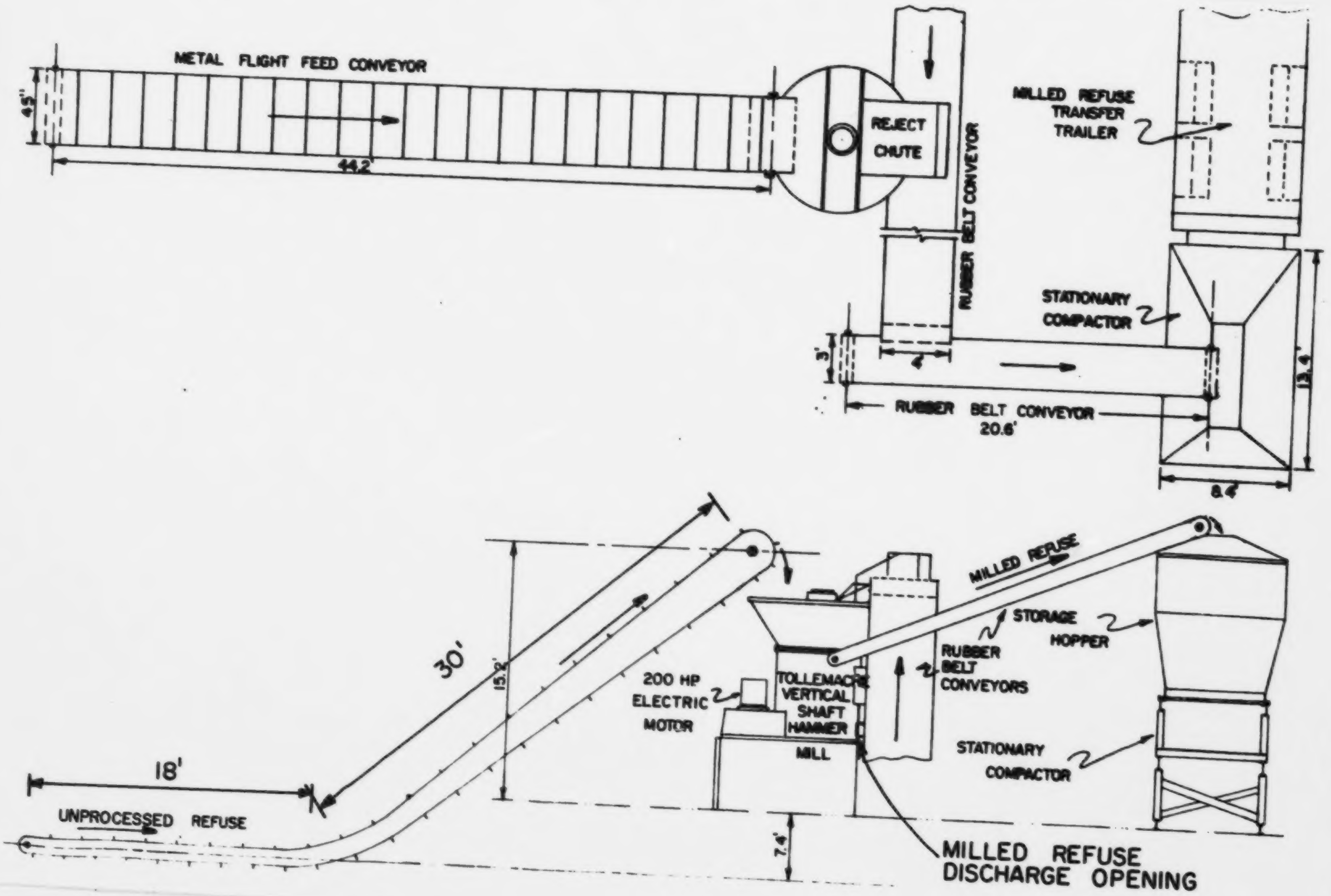

METAL FLIGHT FEED CONVEYOR
45"
44.2'
REJECT CHUTE
RUBBER BELT CONVEYOR
MILLED REFUSE TRANSFER TRAILER
STATIONARY COMPACTOR
3'
4'
RUBBER BELT CONVEYOR 20.6'
13.4'
8.4'
30'
15.2'
18'
UNPROCESSED REFUSE
7.4'
200 HP ELECTRIC MOTOR
TOLLEMACHE VERTICAL SHAFT HAMMER MILL
MILLED REFUSE
STORAGE HOPPER
RUBBER BELT CONVEYORS
STATIONARY COMPACTOR
MILLED REFUSE DISCHARGE OPENING

Figure 9. Tollemache Vertical Shaft Hammermill Showing Feed and Take Away Conveyors

Figure 10. Tollemache Feed Conveyor Showing Tumbling Action of Refuse

Experience with this conveyor at Madison has shown that excessive loading of the conveyor bin is the prime cause of feed delays. These delays can consist of an empty belt moving toward the mill or periods when the conveyor transports unprocessed material in slugs which in turn overburden the mill motor causing the automatic-overload device to activate. Excessive loading of the bin causes refuse bridging near the constriction where the conveyor leaves the horizontal. Thus, although the bin is full and the conveyor is moving, a very inconsistent flow of material is being directed to the mill. To overcome this problem the mill operator only allows 12 cu. yd. of unprocessed material to be in the bin at any one time. The change has resulted in a much smoother operation which has decreased feed delays; although the problem has not been eliminated altogether.

Conveyor Maintenance and Breakdowns:

Preventive maintenance on the conveyor is done once a week. During this period the pulleys are greased and the tracks oiled. A general inspection to locate worn parts or potential trouble areas is also conducted to minimize major breakdowns and to plan an effective repair program.

The most serious breakdowns encountered in the use of this conveyor have occurred when large metal objects in the refuse became lodged between the conveyor rollers and track. The problem, occurring three times in 1971-72, causes the rollers to jump the track resulting in severe damage to the bin walls, conveyor flights, and belt tightners. Although these breakdowns are serious, they are not directly due to inadequacies in the conveyor, but are a result of installing the conveyor inside the Gondard bin conveyor as mentioned previously. The problem centers where the Tollemache conveyor makes its 180° turn at the center of the Gondard bin. In the past, refuse was indiscrimately placed on the top of this area. Thus, under the right circumstances it was possible for metal, etc. to become lodged between the track and rollers. To prevent this situation an umbrella made of steel was constructed over the turn in early 1972, thus preventing refuse from being placed in the area. Since that time no incidents similar to those previously described have occurred.

Another problem that has caused concern is the speed reducer on the conveyor motor. There had been a high incidence of failure - on the average, one every 3 months - of a linkage in the reducer assembly. Although the linkages are not expensive, it is a nuisance to replace them. The problem was traced to excessive wear of the reducer assembly. After an overhaul of this assembly such problems have been eliminated.

Overall Operation:

Although there have been problem areas in the use of the conveyor it is a substantial improvement over the system used in the Gondard operation. The conveyor has held up satisfactorily under very severe conditions.

Most of the problems encountered can be eliminated by modifications to the conveyor itself or in its operation. If must be remembered that this equipment was not specifically designed for transportation of refuse, but has been adapted to it. With this in mind, the experience gained becomes invaluable if applied to other installations.

TOLLEMACHE MILL

The Tollemache Mill, shown in Figure 11, is a vertical-shaft ballistic-rejection hammer mill. The mill consists of funnel shaped outside walls and a somewhat inverted conical rotor which is driven by a 200 h.p. squirrel cage motor.

The outside walls consist of two layers of metal. The outer layer makes up the shell of the unit. The inner layer, crosshatched in the figure, is a removable protective lining. The rotor is made up of three sets of horizontal discs. There are four discs in the first two sets and five in the third. Each disc in a set has equal dimensions, but the diameter of each set increases from the top to the bottom of the mill, thus giving the rotor a conical shape. Hammer tip diameters for the three sets are 33 in. at the top, 38 in. at the middle, and 43 in. at the bottom. Six shafts are afixed, vertically, to each set of discs. The 15-lb. hammers are mounted horizontally on these shafts. The 200 h.p. motor drives the rotor at 1350 r.p.m. and the two are connected by a rubber drive belt. The motor is wired to a 3-phase 440-volt power source.

The funnel shape of the mill shell (Figure 12) and somewhat conical shape of the rotor act both to reduce motor loading and as a ballistic rejection system. Refuse is fed from the top right side (see Figure 11) and enters what is classified as the pre-break section of the machine. Here the material is initially broken up and sufficiently reduced in size in a semi-unconfined area, thus helping to reduce the overall loading on the mill motor. Also it is in the pre-break section where the ballistic rejection of damaging and unmillable material takes place. As the material is being ground, it moves toward the neck of the mill. At this location there are only between 3 and 6 in. of clearance; thus a piece of material that is ungrindable or that has not be sufficiently reduced in size to pass the restriction will be spun around the funnel and will exit the mill via the reject chute which is located opposite the feed opening (not shown in Figure 11). Thus the neck section prevents serious damage to the lower portion of the machine and also controls particle size to a limited degree. Once the material passes the neck section, it enters what is called the grind section. It is here where most of the work is done. The ground material is then discharged through an 11 x 22.5 in. opening at the bottom of the machine.

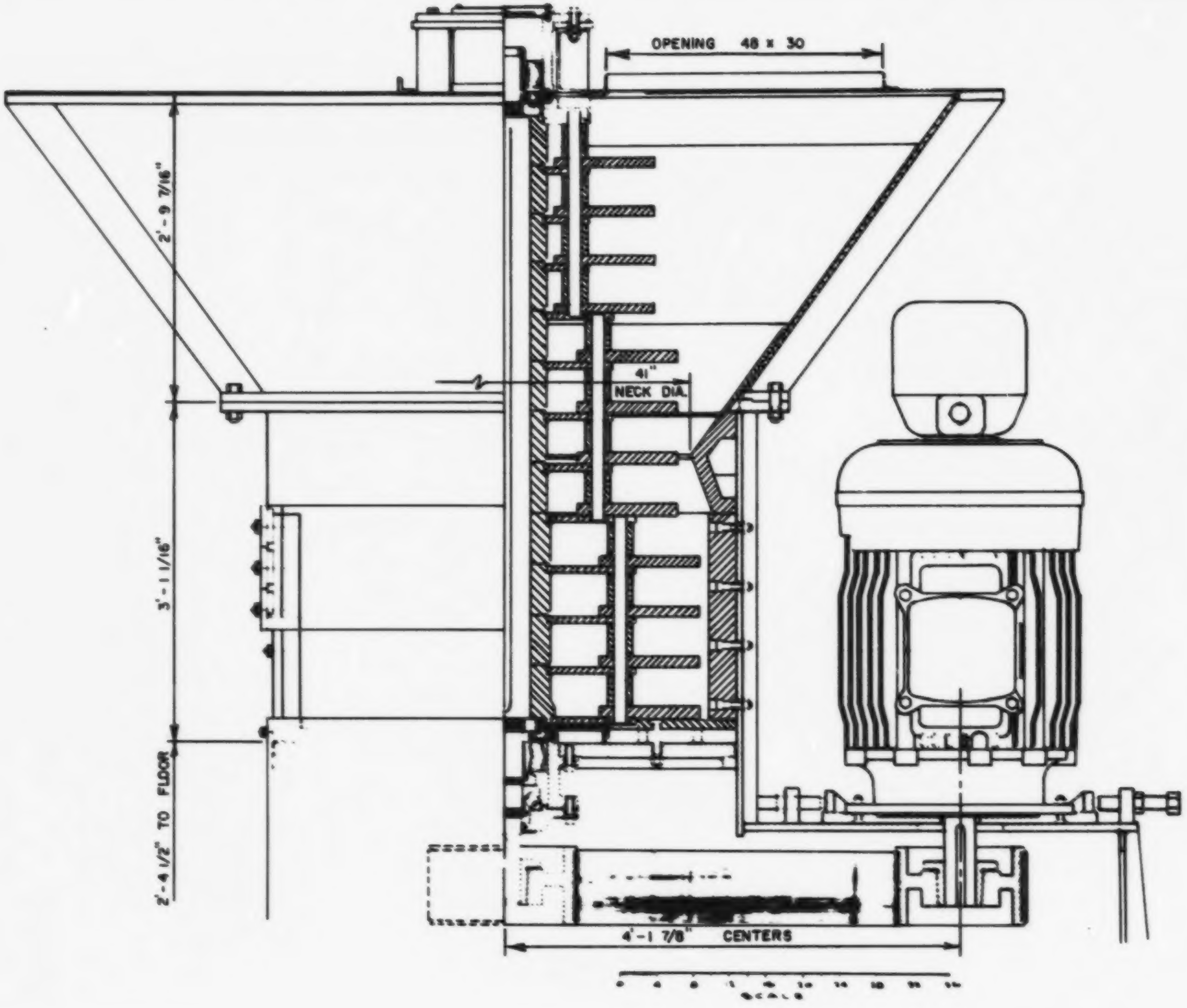

OPENING 48 x 30
2'-9 7/16"
41"
NECK DIA.
3'-1 1/16"
2'-4 1/2" TO FLOOR
4'-1 7/8" CENTERS
SCALE

Figure 11. Cutaway View of Tollemache Mill

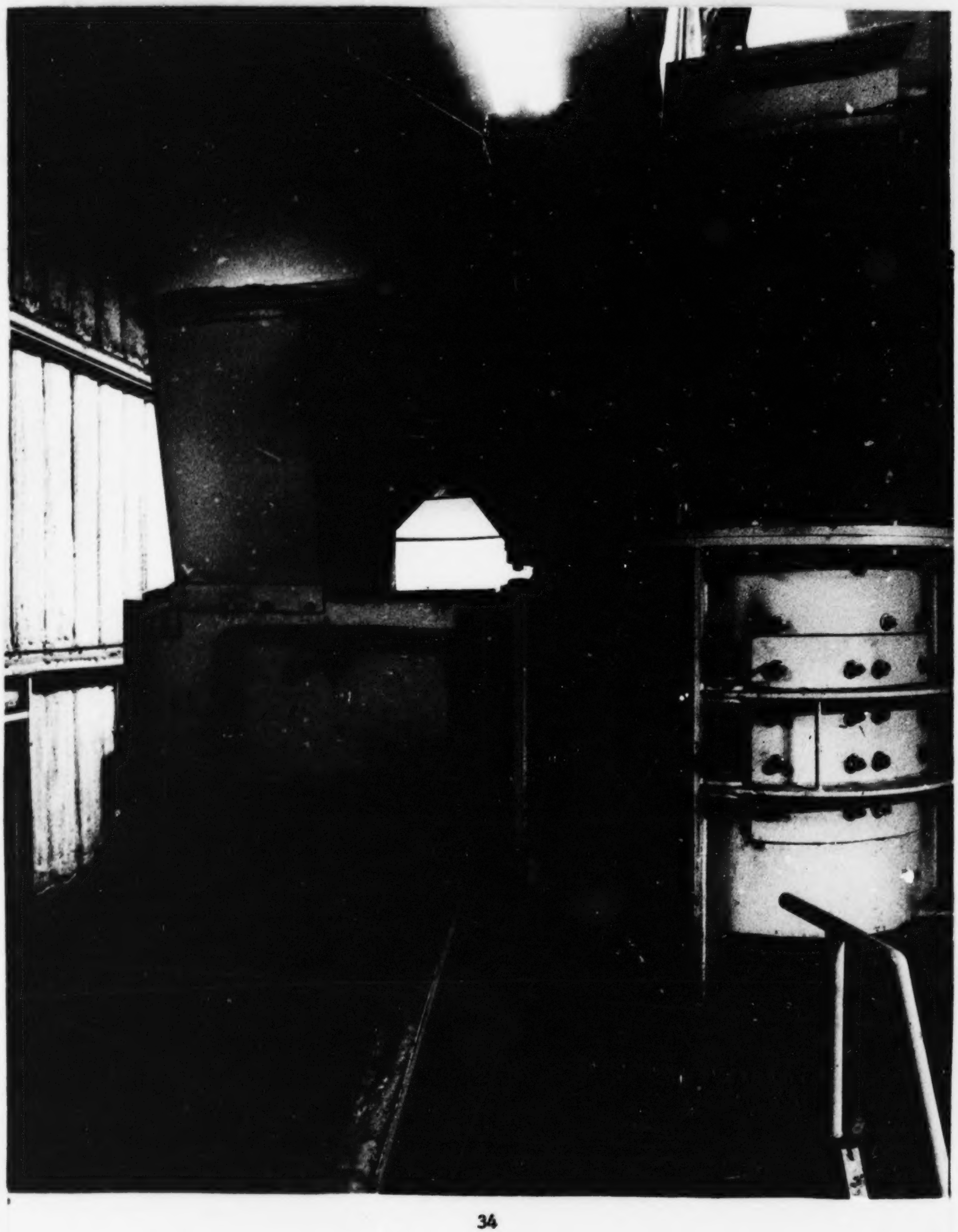


Figure 12. Vertical Shaft Tollemache Mill at Madison, Wisconsin

Daily Operation:

Many factors are related to the daily performance of the Tollemache mill. Some of these are the hammer pattern used, hammer maintenance programs that are followed, feed problems, breakdowns, etc. These factors will be discussed here with the exceptionoof problems related to feeding, discussed above, and removing the ground material, discussed later.

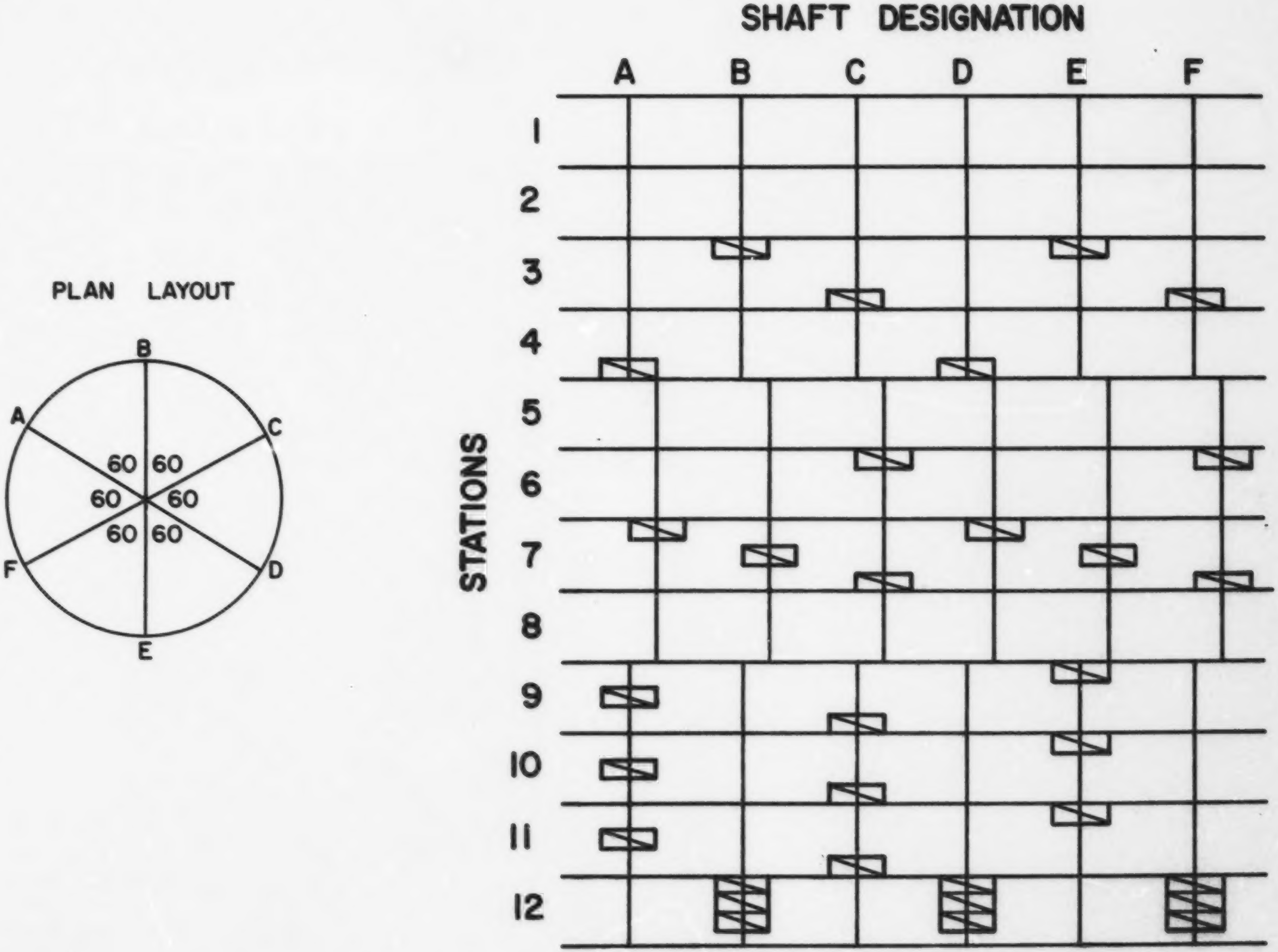
Hammer Pattern

Soon after installation, it was obvious that hammer pattern had a definite influence on mill operation. The original pattern as used in England and initially tried in Madison involved 54 hammers. After a short period of test runs it was evident that such a pattern did not meet the objectives of milling for landfill disposal. The end product was more suitable to a composting operation, and the production rates were very low. Numerous modifications were then made, including reducing the number of hammers to 32. This hammer pattern is shown in Figure 12. After the initial changes were made it was felt that further improvement which would ultimately increase production and afford a smoother operation was possible. Therefore, during an extended test run, other variations in the hammer pattern were evaluated. The following is a compilation of the changes made, reasons they were made, and an explanation of their effectiveness.

As stated previously, Figure 13 shows the pattern in use after the initial reduction in hammers. Stations 1 through 8 are considered the pre-break section, stations 9 through 11 the grind section, and station 12 is the sweep section containing the exit hammers. Stations consist of a hammer and two spacers (3 through 11), three hammers and a spacer (station 12), or three spacers (stations 1 and 2). Vertical shafts are lettered and extend the length of four stations, as mentioned earlier.

Daily observation soon showed that hammer 9E was experiencing more wear than 9A or 9C, and needed replacing every two or three days. The reason is that 9E makes first contact with the material passing from the neck. To remedy the situation, all hammers in station 9 were put on the same level. Thus, excessive wear was distributed equally to three hammers.

Also receiving heavy wear were the undersides of the nine hammers in station 12. Accelerated wear in this area indicated that the milled material was rolling too much before pushed onto the milled refuse conveyor. To alleviate this problem, the hammers and spacers were interchanged. Also, hammers in station 12 were moved to B, D, F from A, D, E while hammers in stations 9, 10 and 11 were moved to B, D, and F from A, C, and E. Elimination of wear to the bottom of the hammers in station 12 was accomplished, but a slight increase in wear to the top of these hammers was noticed.


PLAN LAYOUT
A
B
C
D
E
F
60
60
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60
60
60
SHAFT DESIGNATION
A
B
C
D
E
F
STATIONS
1
2
3
4
5
6
7
8
9
10
11
12

Figure 13. Hammer Pattern Used at Beginning of Evaluation Period

Frequent jams of refuse just above station 1 were prevalent during the first year of operation. An attempt to eliminate these jams was undertaken by placing hammers at 1C and 1F and removing hammers at 3C and 3F. The two hammers in their new location help to pull the refuse down through the feed chute. This modification reduced the frequency of jams.

The final adjustment occurred when a hammer was placed in the lower part of 8A and 8D. Above the neck of the mill are six hammers in station 7. These hammers are placed so as to force any large ungrindable object up through the reject chute thus preventing damage to the machine. While keeping ungrindables above the neck, a restriction was also placed on grinding material. Therefore, two hammers were placed in section 8 to help pull the grindable refuse past the neck section. This adjustment has been worthwhile, since a slight increase in production and a smoother operation have resulted. Figure 14 shows the hammer pattern in use today after the many modifications were made.

Routine Mill Maintenance

Routine maintenance performed on the mill basically consists of hardfacing and/or replacing hammers, shafts, and mill liners. Other areas of the machine, such as reject chute, rotor plates, cone liners, etc., need only periodic attention which is not excessive in time or money compared to the aforementioned items and thus will not be dwelt upon here.

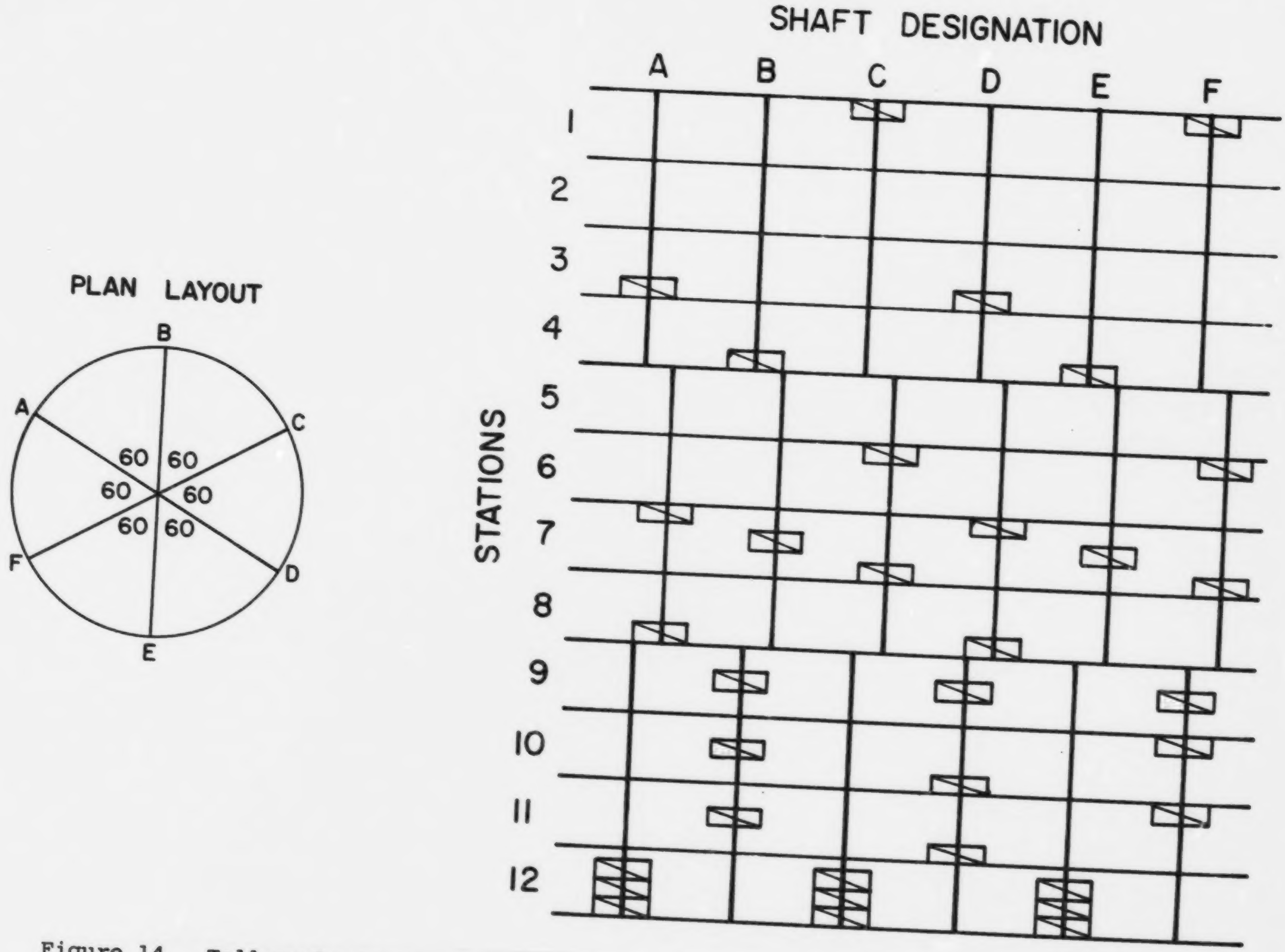
Hammer Maintenance

Experience with the Gondard Mill had shown that a rigorously applied program of hammer tipping significantly reduced hammer wear. Therefore, since the installation of the Tollemache mill, a similar but more intense hammer maintenance program, has been in force. This program consists of an application of Amsco Super 20 hard-facing alloy to each hammer prior to installation into the mill. Hard surfacing, or tipping as it is called, is applied to the wearing edges of the hammer. Wearing edges are in constant contact with the refuse and, consequently, deteriorate more readily than other surfaces of the hammer (Figure 15). Figure 16 shows the dimensions of a typical hammer and the portions that are tipped.

In addition to tipping all hammers before installation, 18 hammers in the lower section of the mill are tipped daily. These 18 hammers do the most work and require constant maintenance. The remaining 26 hammers in the pre-break section are inspected daily and tipped when deemed necessary.

Hammer Wear - Tipping vs. Not Tipping

On a full-scale operating basis, a set of 34 hammers maintained by tipping will process 1000 to 1200 tons of refuse. A set of untipped hammers will process only 400 to 500 tons. From this comparison it is


PLAN LAYOUT
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SHAFT DESIGNATION
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C
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F
STATIONS
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Figure 14. Tollemache Hammer Pattern in Use at Madison at end of Evaluation Period.

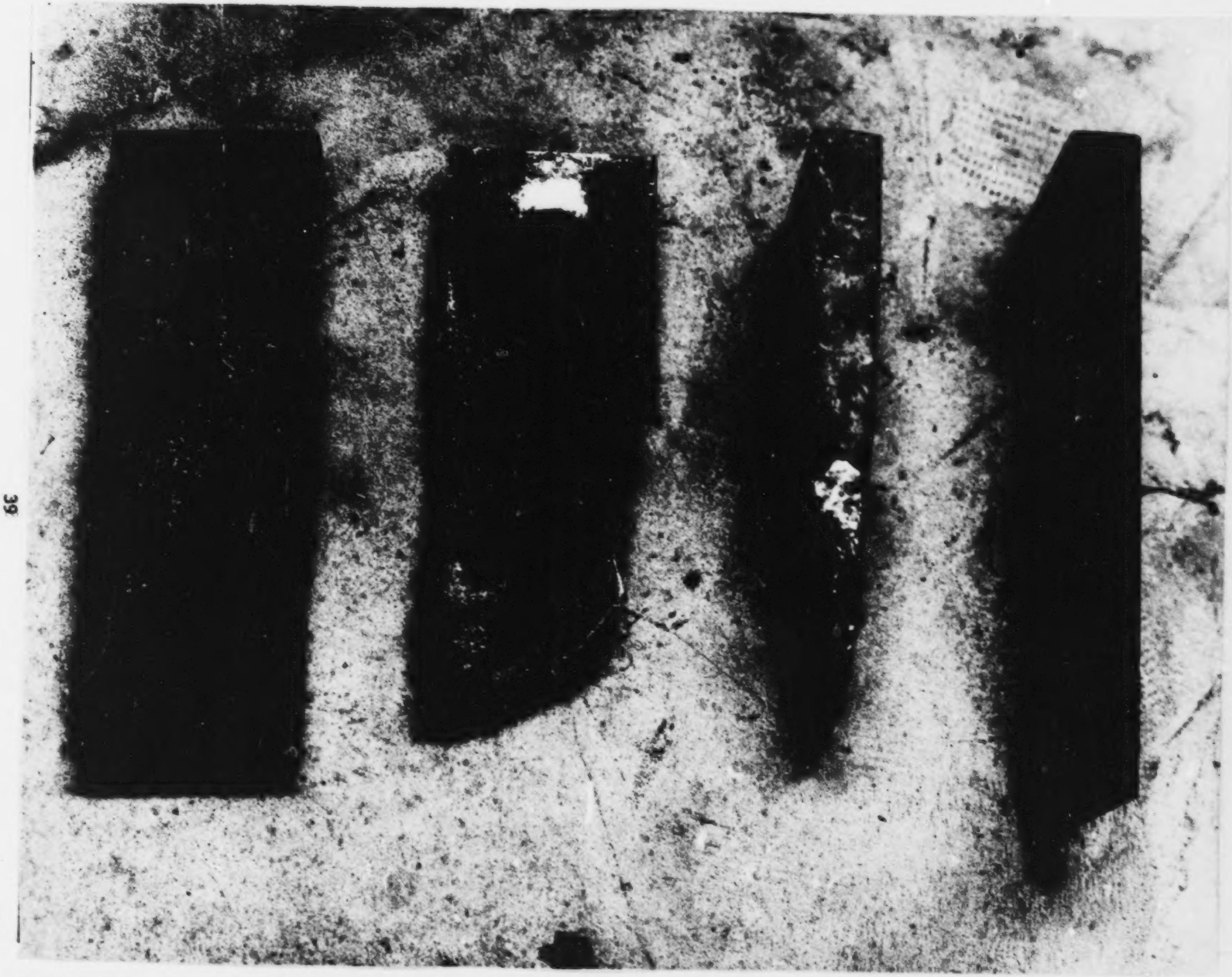


Figure 15. Tollemache Hammers; New (Either Side), and After Four Days Use

obvious that tipping more than doubles hammer life; but it is not evident that tipping is economical. To study the economics of tipping, a test was performed using tipped and nontipped hammers in the mill, under normal plant operating conditions. The comparison was made on a cost/ton basis, and the results showed that a tipping program, if applied rigorously, will save approximately 23 cents/ton over a program using nontipped hammers. The entire savings was due to the lower number of hammers used in the tipping program. Labor and welding materials for the tipping program were about equal to labor for hammer changing alone in the nontipped program. A more complete and in-depth presentation of the test is presented in Appendix G.

Mill Liners

The hull or shell of the mill is protected by liners or wear plates. The liners are made of a manganese steel alloy and are replaceable.

For the first 2 years of operation no attempt was made to reduce liner wear because the mill was run on a test basis and the liners did not wear significantly. A set of untipped liners was found to last through approximately 12,000 tons of refuse. In January 1972 the plant was put on a two-shift basis with the prospects of 45,000 tons of refuse being processed by the mill annually. At that rate of production four sets of liners would be needed each year. At over $1300 per set and with 32 man-hours of labor needed per change the outlook was very expensive. Consequently, methods of increasing liner life were investigated. The method first looked at was hardfacing. At this point some difficulty was experienced, since a welding rod made of an adequate hardfacing alloy that would deposit weld vertically was needed. After trying many types of rods, the Stoody 3/8 in. # 57159 proved to be the most efficient. Liners are now extensively hardfaced prior to installation. They are also touched up in the machine when excessive wear is noticed.

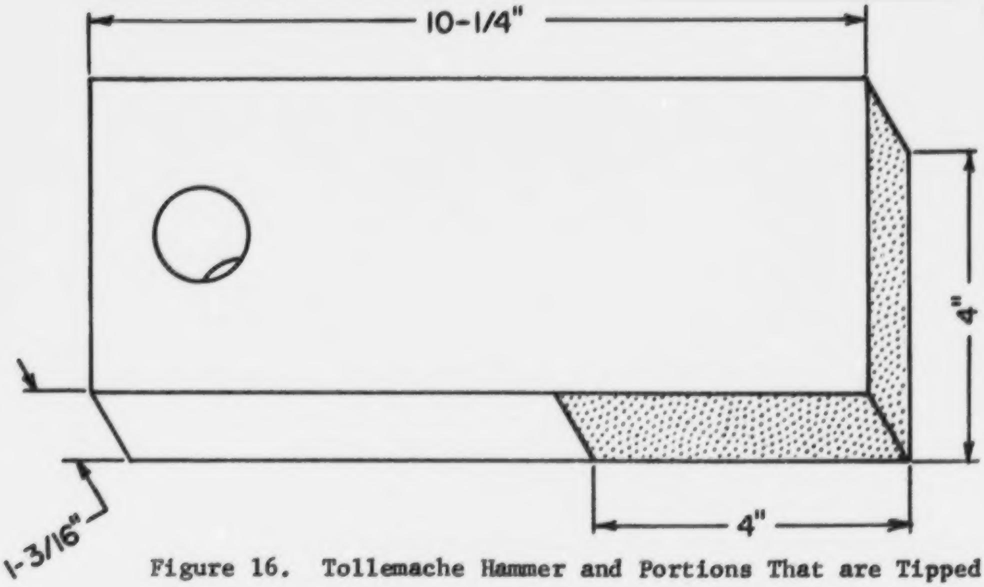


Figure 16. Tollemache Hammer and Portions That are Tipped

Early results indicate that this procedure has increased liner life to 20,000 tons/set; this is almost double that of untreated wear plates. Other methods to increase liner life are now being studied, such as rotating or inverting them periodically to evenly distribute wear and welding manganese rods to them to prevent wear of the base metal itself.

Operational Aspects:

Production Rates

Mill production rate is a ratio of tons of refuse milled and operating time. It is measured in tons/hr. (TPH). Two such rates are usually computed; one using total running time, and the second total running time plus down time. Down time includes mill jams, breakdowns, etc. These rates are referred to as operational and overall production rates, respectively. The operational rate indicates the efficiency at which the machinery is functioning and the overall rate indicates the efficiency at which the plant is operating. Neither rate takes into account routine maintenance or periods when no solid waste is present to be fed into the mill.

The Tollemache mill is rated at an operational capacity of 15 TPH. On a daily basis these rates have ranged from 11 to 20 TPH. On an average it is near 14. The overall production rate has been about 0.5 TPH lower than the operational. This fact indicates that the machine operates with a minimum of down time.

A distinct seasonal variation in production rate has been noticed at Madison which is related to the moisture content of the refuse. During late spring, summer, and fall when the average moisture content of the refuse ranges from 35 to 45 percent on a dry weight basis; the highest production rates have been experienced. In late fall and winter, when moisture content is only 15 to 20 percent, production rates reach a minimum. This fact was brought out during two evaluations of the mill. One was done during the summer and early fall of 1970. The other during the winter of 1971. Table 5 shows a compilation of production rates on a monthly basis for the two test periods. Monthly average moisture content is also indicated.

The table shows that higher production rates were achieved during periods of high moisture content. Thus, when discussing mill production rates, the figures should also be cited in dry tons of refuse per hour. In this manner rates can be calculated for different applications in other parts of the country. For this reason, Table 6 is presented using dry tons milled and computing a production rate in dry tons/hr. A comparison of dry tons/hr. (DTPH) in Table 6 shows that the mill processes refuse at nearly the same rates and in fact the seasonal variations are due to moisture content changes. Because of this, production rates will be expressed both in TPH and DTPH throughout the remainder of this report.

TABLE 5

Operating and Overall Production Rates for Tollemache Mill

	Tons Milled	Time (Hours)		Prod. Rate (TPH)		Moisture Content Dry Weight
		Operational	Overall	Operational	Overall	
July 6 to 31, 1970	1480	100.4	104.0	14.72	14.22	33%
August 1970	1573	104.9	107.7	15.01	14.62	35%
September 1970	1701	122.5	125.3	13.89*	13.58*	44%
October 1 to 9, 1970	564	38.0	38.3	14.82	14.72	32%
July 6 to October 9, 1970	5318	365.8	375.3	14.53	14.18	37%
February 4 to 28, 1971	1105	86.40	87.06	12.79	12.69	25%
March 1 to 31, 1971	1519	118.11	121.61	12.86	12.50	22%
February 4 to March 31, 1971	2624	204.51	208.67	12.83	12.58	23%

* During two periods in September, linkage on the variable speed drive of the mill conveyor was broken. Thus, the conveyor could only operate at its slowest speed. This was a feed problem, not a mill deficiency.

TABLE 6

Operating and Overall Production
(Dry Tons Per Hour)

	Dry Tons Milled	Production Rate - DTPH	
		Operating	Overall
July 6 to 31, 1970	1110	11.05	10.67
August 1970	1165	11.11	10.82
September 1970	1180	9.64*	9.43*
October 1 to 9, 1970	425	11.19	11.10
July 6 to October 9, 1970	3880	10.61	10.35
February 4 to 29, 1971	885	10.25	10.18
March 1 to 31, 1971	1245	10.55	10.25
February 4 to March 31, 1971	2130	10.40	10.20

* During two periods in September, linkage on the variable speed drive of the mill conveyor was broken. Thus, the conveyor could only operate at its slowest speed. This was a feed problem, not a mill deficiency.

Power Consumption - Mill

Mill power consumption is broken down into two distinct categories - kilowatts (kw) and kilowatt hours (KWH). Kilowatts provide a measure of peak demands for power during a specific time period. Kilowatt hours are a measure of the actual energy use. As such, kilowatts are not a function of tons milled, but kilowatt hours are.

Mill demand ranges from 110 to 160 kw/mo. The highest values are experienced from November to March; but since the cost of demand is billed on the highest demand in the preceding 12 mo. period the range of demand is not important. Energy use measured in kilowatt hrs./ton (KWH/T) follows much the same pattern peaking in the winter and reaching lows during late spring, summer, and early fall.

Extensive power data were kept during the two experimental evaluations of the Tollemache mill. Table 7 shows the summaries of data collected during those periods. Notice that energy use during the summer evaluation was 2.5 KWH/T lower than during the winter tests. Also notice that on a dry ton basis the summer evaluation had a power consumption over 2.1 KWH/T lower than the winter test. Thus, a definite relationship between KWH/T and moisture content is not evident.

Power Consumption - Mill Accessories

Mill accessories include the feed conveyor, final transfer conveyor, stationary compactor, welding machine, etc., all of which operate from a 3-phase 440-volt source. Unfortunately, no equipment was available to secure power data from the mill accessories on an individual basis until January 1972, when a single power meter was installed to record data from the stationary compactor. Prior to that time, all accessories had been lumped together. Data from both evaluations obtained has indicated that power consumption for mill accessories as a whole is about one-fourth that of the mill itself. Power data obtained from the stationary packer hookup itself will be discussed in the portion of the report dealing with evaluation of a two-mill, two-shift operation.

Mill Jams and Major Breakdowns

The mill itself is the most reliable piece of equipment in the overall system. Nonetheless, the mill has not been completely trouble free. Some problems have included internal jamming, explosions, and trouble with the radial and thrust bearing on the main shaft.

Internal Jams

An internal mill jam differs from a feed jam in that it occurs in the mill proper, usually in the grind section. Such jams have occurred when heavy wire, bed springs, tires, etc., inadvertently enter the machine. When this happens the mill motor becomes overloaded and circuits are broken. The jams, especially when wire is involved, stop operations for about an hour while the machine is being cleared.

7

TABLE 7

Comparison of Power Data For Tollemache Mill Alone (1970-71)

Period I	KWH	Tons Milled	KWH/Ton	Dry Tons Milled	KWH/ Dry Ton
July 6-31	10,672	1480	7.20	1110	9.60
August	9,856	1573	6.26	1165	8.46
September	10,288	1701	6.04	1180	8.70
October 1-9	3,152	564	5.59	425	7.42
Overall	33,968	5318	6.37	3880	8.75
Period II					
February 4-28	10,272	1105	9.30	885	11.60
March 1-31	12,864	1519	8.46	1245	10.31
Overall	23,136	2624	8.82	2130	10.86

During the first few months after the machine was installed, these jams occurred about once a week. Thus, elimination of this problem became crucial. Prevention has involved close scrutiny of incoming refuse. Any article deemed damaging or able to cause jams is removed from the incoming stream of refuse on the storage floor. This material is small in quantity. It is landfilled separately, then covered with the milled refuse. Also, since Madison has a bulky item pickup, refuse pickers are instructed not to collect potential damaging articles. The combination of minor separation at the plant and separation on the collection routes has minimized internal jams to the point that, on the average, only one is experienced a month.

Explosions

As the refuse is being processed, a constant array of sparks is being produced by contact of the hammers and metal in the refuse. Therefore, if a can of paint thinner, unbroken bottle of alcohol, or a container with any other flammable liquid happens to enter the mill intact, an explosion is likely. The explosions themselves do no notable damage to the mill, but they are a potential hazard to personnel working in the area. During the 3 years of operation using the Tollemache mill, only five or six such explosions have occurred. After the first two incidents, an explosion chamber was constructed above the mill. The chamber consists of heavy steel chute leading from the top of the mill to the plant roof. Here the chute is capped with light sheet metal to provide minimum resistance to rapidly expanding gases. Experience has shown that the explosion chamber functions quite well.

Bearing Problems

By far the biggest concern in respect to the mill itself has been the bearings that support the rotor. Referring to Figure 11, notice that at the extreme upper and lower parts of the rotor are three bearings. The two similar bearings are radial bearings; the other is a thrust bearing. It has been the unfortunate experience at Madison to have to replace two lower radial bearings and four thrust bearings.

In the original design, the thrust bearing was to draw the cooling and lubrication oil from a reservoir and throw it up to the two radial bearings. About a year after installation, the thrust bearing burned out and was promptly replaced. The replacement bearing was manufactured in the United States and was not exactly the same as the original manufactured in England. Less than a week after replacement this new bearing also burned out, as did a radial bearing. At this time it was decided that the new type bearing was not drawing enough oil to cool itself and consequently not passing enough up to the radial bearings. Thus, an oil pump was installed to force-circulate oil to all bearings. This worked well until about a year later when the thrust bearing again needed replacement. It was promptly replaced and burned out 3 mo. later, as did another radial bearing. At this point a careful reevaluation of what had taken place over the last year and a half revealed the problem was not directly related to the circulation of oil but was the result of the rotor shaft moving up and down. During replacement of the rotor, it was discovered that a retainer nut holding the rotor assembly together had worked loose, thus allowing the entire rotor assembly to jump up and down a fraction of an inch. This resulted in abnormal stress on the bearings, and they burned out. A key has been placed over the retainer nut in the new assembly, and no bearing problems have been experienced since that time.

STATIONARY COMPACTOR AND TRANSFER TRAILERS

Prior to installation of the Tollemache mill, continuous-cycling refuse packer trucks were used to transport milled refuse totthe landfill site. The use of these trucks was inefficient in conjunction with the less productive Gondard mill and proved to be even more so with the more productive Tollemache mill. It would take 20 to 30 min. to fill a packer truck and 10 to 15 min. to empty one. Therefore, one man would constantly have to be watching and switching full trucks while the mill was operating. To free this man for other duties, and to provide increased capacity for removal of milled material, a Heil stationary compactor system was installed.

The stationary compactor, similar to those used in transfer stations, is used to compact the ground refuse into a 75-cu.-yd. transfer trailer (Figure 17). A 35-cu.-yd. storage hopper was installed above the compactor to allow the mill to operate while trailers are being switched (Figure 18). The storage hopper is outfitted with an electric eye that automatically turns off the feed conveyor to the mill if the bin becomes full. The electric eye eliminates spillage from the bin and backups on the final transfer conveyor.

Following are some of the characteristics of the compactor trailer operation in conjunction with the Tollemache mill:

1. It takes 70 to 80 min. to fill one trailer.
2. A full trailer will net from 16 to 20 tons of milled refuse.
3. One can switch and empty trailers in five min.
4. Time to switch and empty trailers is about 20 min. where haul distance, round trip, is less than 0.5 mi.
5. The 35-cu.-yd. storage hopper provides enough volume to allow milling to continue while normal switching of trailers take place.
6. The use of the compactor and trailers has given one man an extra 50 to 60 min. per trailer load for other duties around the plant.

Trouble Areas:

Since the plant is located on an operating landfill site, only two trailers and one tractor were purchased. The trailers are made by the Heil Company and consist of 75 cu. yd. of storage space, with a hydraulicly operated ram to eject the milled refuse. The hydraulic

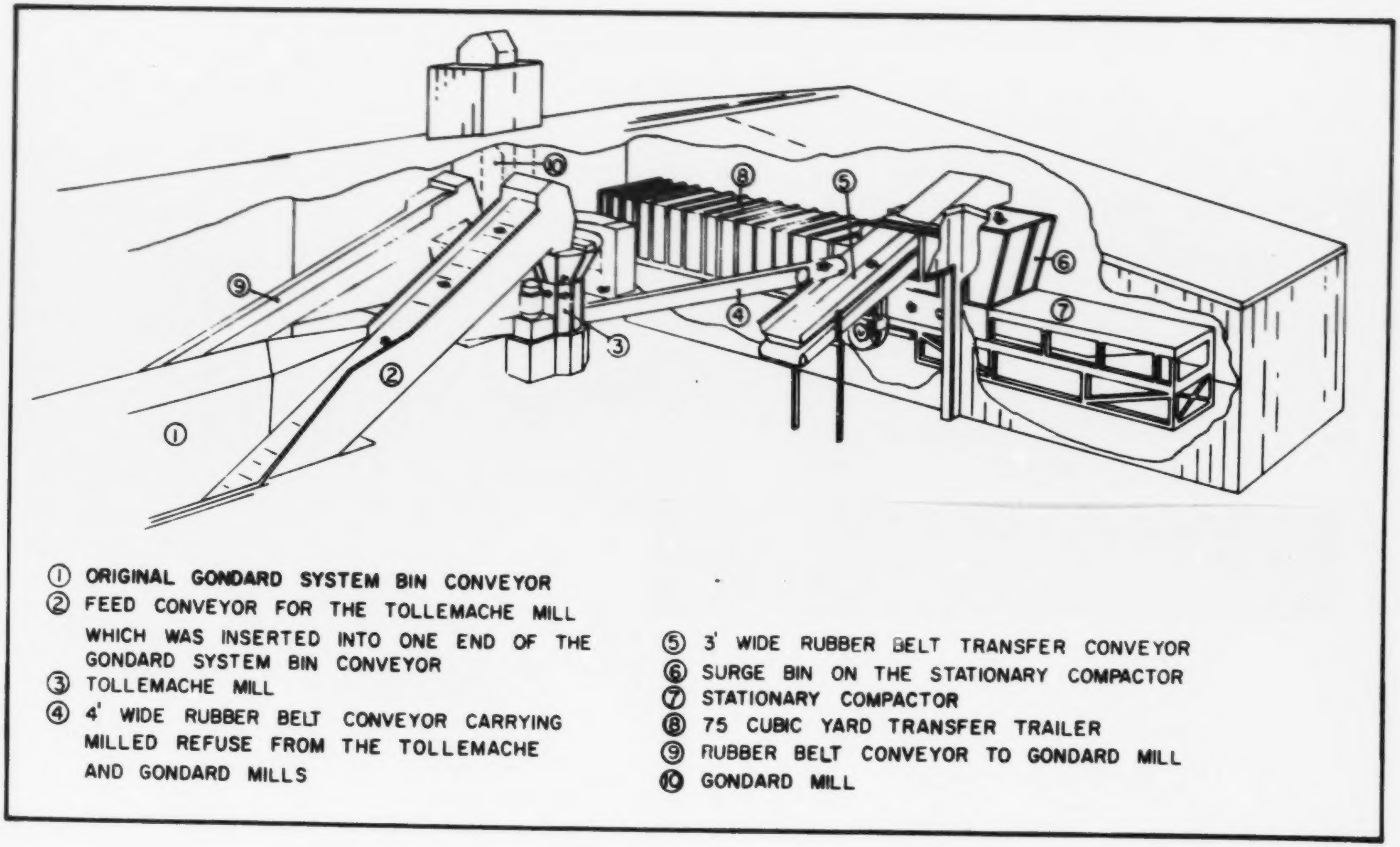

①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
① ORIGINAL GONDARD SYSTEM BIN CONVEYOR
② FEED CONVEYOR FOR THE TOLLEMACHE MILL WHICH WAS INSERTED INTO ONE END OF THE GONDARD SYSTEM BIN CONVEYOR
③ TOLLEMACHE MILL
④ 4' WIDE RUBBER BELT CONVEYOR CARRYING MILLED REFUSE FROM THE TOLLEMACHE AND GONDARD MILLS
⑤ 3' WIDE RUBBER BELT TRANSFER CONVEYOR
⑥ SURGE BIN ON THE STATIONARY COMPACTOR
⑦ STATIONARY COMPACTOR
⑧ 75 CUBIC YARD TRANSFER TRAILER
⑨ RUBBER BELT CONVEYOR TO GONDARD MILL
⑩ GONDARD MILL

Figure 17. Tollemache Mill Installation With Transfer Packer Station

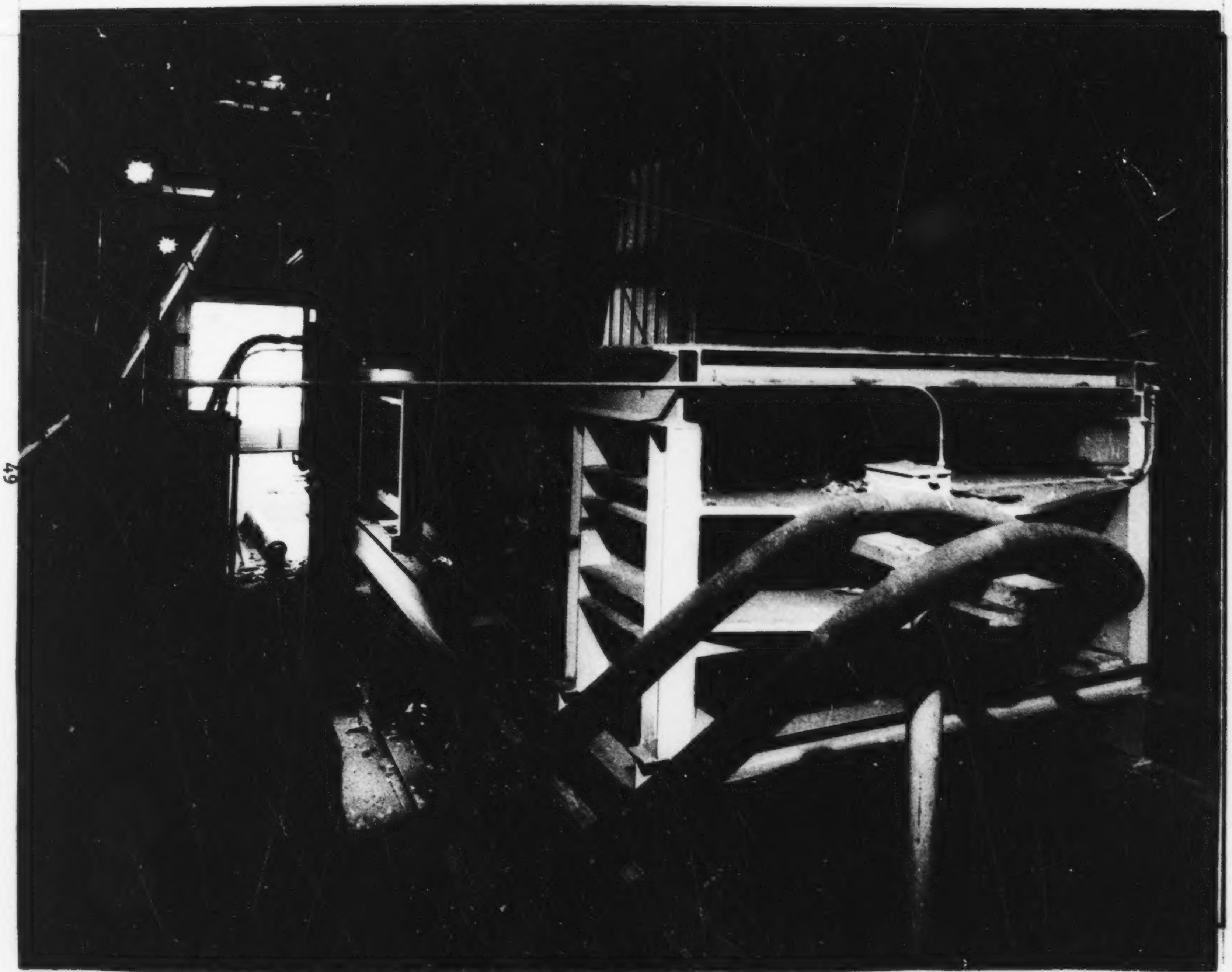


Figure 18. Stationary Compactor With 35 Cu. Yd. Storage Hopper

system is operated by an 80 h.p. motor affixed to the front of the trailer. The rear door is of the guillotine type for filling and has a 360 h.p. gasoline engine. The fact that the tractor has a gasoline engine has caused some problems. Mainly it does not have sufficient torque at low speeds, thus making it hard to operate with a full trailer. Some engine overheating difficulties have also plagued the tractor. It seems that the radiator gets completely plugged with dust, cutting off circulation of air. Constant maintenance on the radiator is needed to keep it open and prevent engine damage.

In the very near future Madison plans to transport the milled material to other outlying landfills. In anticipation of this plan, it has acquired two new tractors and trailers. The new trailers are similar to the original ones except they have swinging gate rear doors and their hydraulic system will be powered by the tractor itself. The new tractors are manufactured by Heil and contain 225 and 195 h.p. diesel engines for over-the-road operation.

TOLLEMACHE ECONOMICS

As stated previously, two experimental runs using only the Tollemache mill were undertaken in summer 1970 and winter 1971. During both of these shakedowns, extensive cost data were collected on labor, power, repairs, replacement, etc. Thus a comparison is possible between summer and winter operations of the same plant and equipment. To make the comparison equitable, changes in wages and other increases in cost between the two runs must be considered. Therefore actual and adjusted cost will be presented for the data obtained during 1970. The adjusted cost will be computed using the wages and prices in effect during the 1971 test. All wage rates, performance data, utility use, amortization data, and prices used in the calculation of costs are presented in Appendices H, I, and J.

Cost of the operation is best presented in two general categories - that of milling, to include conveyance of the unprocessed and milled material; and that of transportation to the final disposal site, to include the stationary packer and hauling equipment.

MILLING COSTS

Table 8 contains an extensive breakdown of the costs incurred during the two test periods on a per-ton basis. Note that one must realize the implications of expressing costs on a per-ton basis in order to use such a figure properly. Seriously affecting these figures are such uncontrollable factors as: 1) The average moisture content of the refuse being processed; 2) the characteristics of the refuse; 3) the type of material - residential, commercial, industrial, or some combination of these; and 4) geographical location of the plant. Therefore the costs stated here can be viewed only as an indicator of what was experienced at one installation and as such they cannot be expected to be generally applicable to other locations. A detailed analysis of the data presented in Appendices H, I, and J, must be undertaken to determine to what extent the figures obtained at Madison are valid for any similar installation that is being considered.

Table 8

Tollemache Milling Costs

	Test Period #1*		Test Period #2**
	$/Ton	Adjusted $/Ton	$/Ton
Labor* **	$2.395	$2.758	$2.577
Depreciation (See Appendix H)	1.134	1.134	1.327
Hammers & Shafts	0.137	0.137	0.206
Power	0.245	0.248	0.351
Welding Rod	0.033	0.033	0.031
Plant Supplies	0.029	0.029	0.042
Front End Loader Maintenance	0.055	0.068	0.079
Gas - Heat	0.000	0.000	0.154
Lighting	0.052	0.059	0.105
Water & Sewer	0.001	0.002	0.006
Contracted Repairs	0.011	0.013	0.040
Replacement Parts	0.038	0.045	0.074
Total	$4.130	$4.562	$4.992

* 14 wks. - July 6 - October 9, 1970, 5318 tons milled, average - 77 tons/day and 5.3 hrs. machine time/day.

** 8 wks. - February 4 - March 31, 1971, 2624 tons milled, average - 66 tons/day and 5.1 hrs. machine time/day.

*** Includes all fringe benefits. (See Appendices I and J)

An analysis of Table 8 indicates that on an adjusted basis the cost per ton for period 1, summer 1970, is about $0.43 less than period 2, winter 1971. There are two prime factors contributing to this. First is the fact that on the average less tons were milled per day during period 2; thus, relatively stable or fixed costs such as amortization increase on a per-ton basis. The decrease in average milled tons per day is due to seasonal variations in refuse quantities. Also, during period 2 gas and lighting costs increased due to changed weather conditions.

The average overall adjusted cost per ton of approximately $4.80 can be misleading. It must be remembered that this figure has been derived from experimental runs. At the time of the tests the plant was only operating at three-fourths of its rated capacity. At full capacity the plantccould average 90 to 100 tons/day as compared to the 65 to 75 experienced during the tests. This would mean that fixed costs, labor and amortization, would be reduced by 23 percent to an average of $3.70/ton. This fact is borne out more clearly in following portions of this report.

STATIONARY PACKER AND HAUL COSTS

Table 9 contains the detailed breakdown of costs on a per-ton basis for test periods 1 and 2. The actual cost as well as adjusted cost per ton is presented for period 1 as in Table 8.

Table 9

Stationary Packer and Haul Costs
During Tollemache Evaluation

	Test Period 1*		Test Period 2**
	$/Ton	Adjusted $/Ton	$/Ton
Depreciation (See Appendix H)	$0.488	$0.448	$0.524
Labor (Driver)***	0.120	0.137	0.147
Power	0.016	0.019	0.023
Tractor & Trailer Maintenance	0.018	0.027	0.017
Packer Maintenance	0.010	0.012	0.012
Total	$0.612	$0.643	$0.723

* 14 Weeks in length - July 6 - October 9, 1970, 5318 tons milled, average - 77 tons/day and 5.3 hrs. machine time/day.

** 8 Weeks in length - February 4 - March 31, 1971, 2624 tons milled, average - 66 tons/day and 5.1 hrs. machine time/day.

*** Includes all fringe benefits. (See Appendices I and J).

Again, packer and haul costs as shown are misleading and cannot be assumed to reflect what would actually be expected under standard operating conditions. At full capacity, 90 to 100 tons/day, the overall average cost per ton as indicated in Table 9 would be reduced by nearly 24 percent from $0.70/ton to approximately $0.53/ton.

The costs of landfilling milled refuse are presented in Section III-D of this volume.

III - C - Two-Mill, Two-Shift Operation

As early as the summer of 1969, Madison was preparing to expand the existing physical plant and abtain additional equipment in order to operate on a two-shift basis and thus increase production. A plan called for the city to achieve this goal by late 1971. The first step was taken in the winter of 1970-71 with completion of the plant expansion. The second step was completed with the conclusion of the second and final Tollemache evaluation in early 1971. The third phase of the plan was attained by December 1971 when a competent plant supervisor and three additional men to man the second shift were hired. Finally, in January 1972, the two-shift operation utilizing both the Gondard and Tollemache mills was initiated. The following portion of this report discusses the gradual transition from a one-shift to two-shift operation, the success and problems encountered, and the economics of increased plant production from January 1 to June 30, 1972.

PLANT OPERATION

Description of Expanded Facilities:

In the design of the two-shift operation several important assumptions were made: 1) the combined average overall plant production would be 20 to 22 tons per hour and 2) the mills would be able to operate an average of 13 to 14 hours out of a 16-hour day. Thus the design capacity of the plant would be near 280 tons per day. Assuming that a storage capacity of 1.25 times the design capacity was needed, it became evident that the original plant with a storage of less than 100 tons was inadequate. Therefore the city undertook a $130,000 plant expansion. Included in the expansion was a special research area devoted to experimentation in paper recovery that is not directly related to plant functions. Therefore the net expense devoted directly to daily plant operation was approximately $98,000.

Figure 19 shows a floor plan of the original facility overlaid by that of the expanded facility. An important thing to notice is that no modifications were made to the mills or conveyor systems. The plan indicates that usable floor space was expanded from 6,650 sq. ft. to 13,150 sq. ft. At an average unprocessed stored refuse height of 16 ft. and density of 400 lbs./cu. yd., the increased floor space would net a stored volume equal to 310 tons vs. 85 tons for the original building. Also included in the expansion were a control room, office, conference room, and workshop (Figure 20).

The control room, located on the second floor, is the heart of plant operation. It contains all systems controls and allows the operator a clear view of the dump floor, both mills, their respective feed systems, and the first portion of the milled refuse takeaway system. A closed circuit television setup allows the operator to view the final takeaway conveyor and stationary compactor. The office located adjacent to the control room was provided for use by the plant supervisor. The workshop is used as a

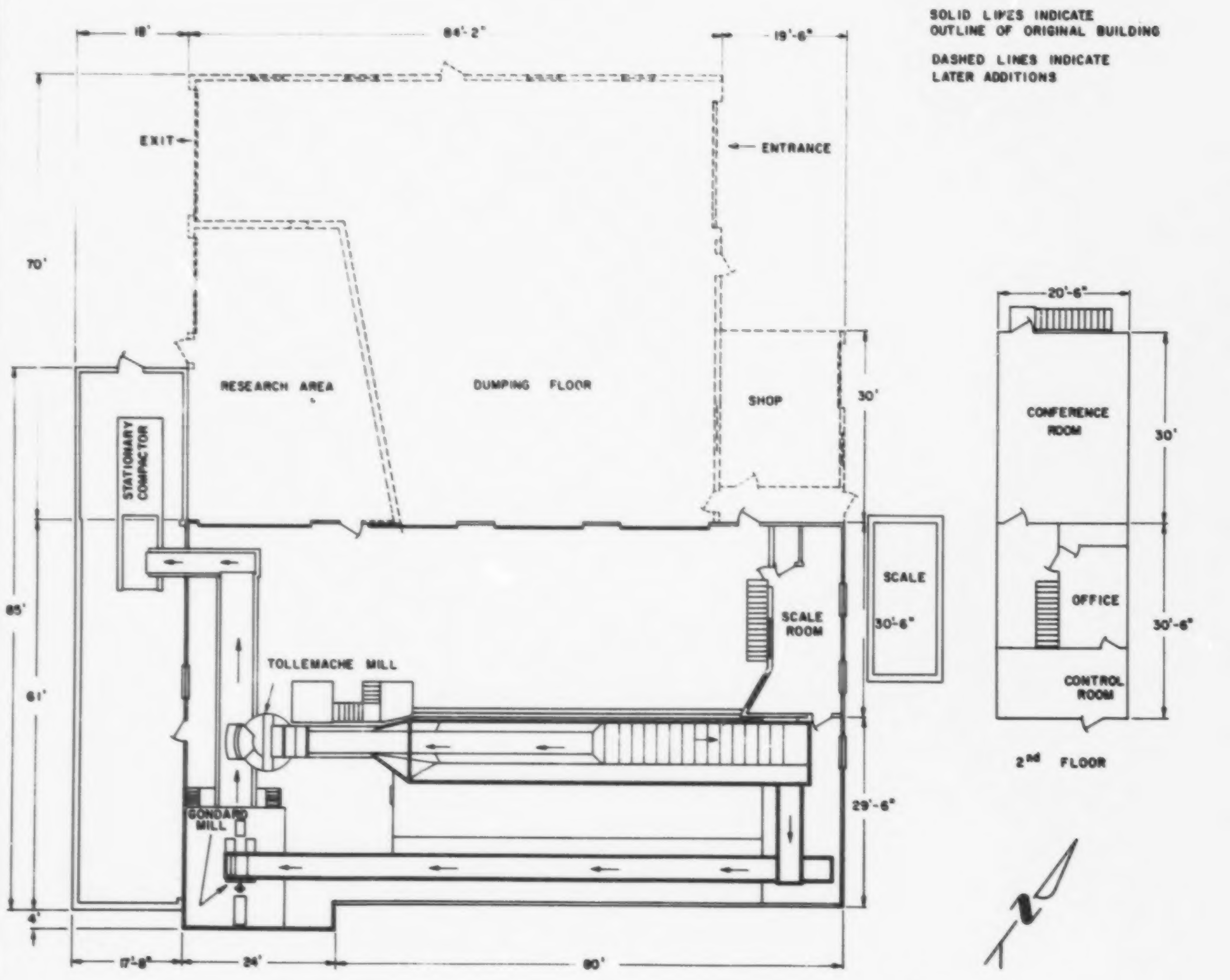

SOLID LIPES INDICATE
OUTLINE OF ORIGINAL BUILDING
DASHED LINES INDICATE
LATER ADDITIONS
18'
84'-2"
19'-6"
EXIT
ENTRANCE
70'
RESEARCH AREA
DUMPING FLOOR
SHOP
30'
STATIONARY COMPACTOR
SCALE
30'-6"
SCALE ROOM
85'
61'
TOLLEMACHE MILL
29'-6"
GONDARD MILL
4'
17'-8"
24'
80'
20'-6"
CONFERENCE ROOM
30'
OFFICE
30'-6"
CONTROL ROOM
2nd FLOOR

Figure 19. Madison Refuse Milling Plant

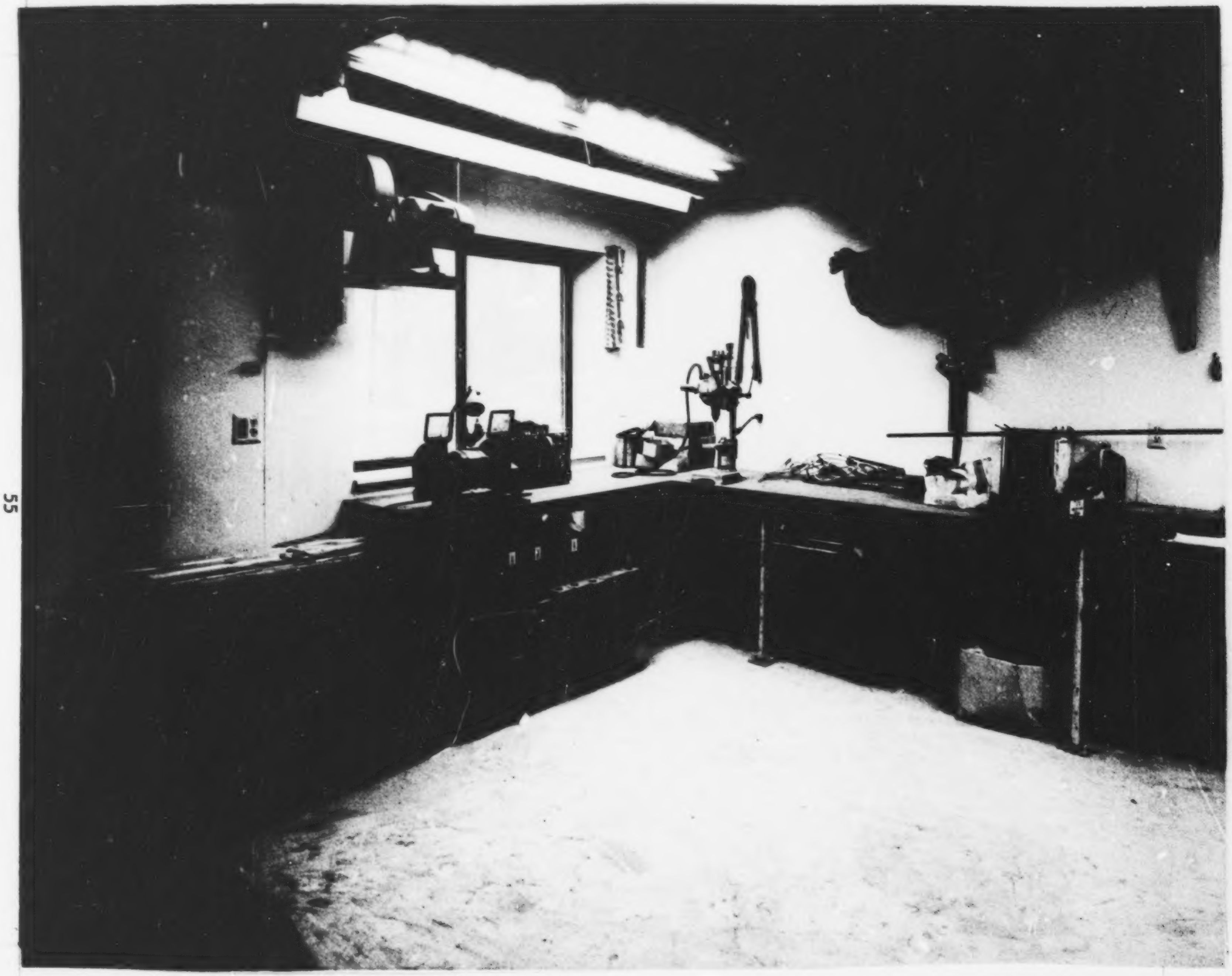


Figure 20. Maintenance Shop for Welding and Repairs at Madison's Milling Plant

tool room, storage room, and work area. Located below the control room is the scale room which was not modified during expansion. The conference room which waslocated on the second floor and is used primarily for plant tours. It is not a necessary facility and could have been eliminated from the building design without hindering plant operations.

Additional Equipment Requirements:

Three pieces of equipment were acquired as a direct result of plant expansion. A new larger front-end loader was bought to handle the increased volume of materials. The new machine is a rubber tired 75M model made by Michigan. Bucket capacity is 3 cu. yd. Also acquired was a new Ford diesel tractor. The new 225 h.p. tractor was needed to reduce man hours devoted to clean-up.

Personnel Requirements:

During the initial five years of operation, three men were used to perform all plant functions. Supervision was provided on a limited basis from the city's street department. During evaluations of the Gondard and Tollemache systems it was determined that three men were sufficient to perform plant functions. It was also learned that full-time supervision was needed to create an efficient operation. Thus, when preparations for two shifts were made it was decided that three additional men would be hired to man the night shift. It was also decided to hire a full-time supervisor. It was assumed that the increase in labor cost by the addition of a seventy man would be offset by increased efficiency in plant operation. This has been a valid assumption as indicated by the economic data presented later in this report.

The supervisor was carefully selected from a field of experienced personnel and commenced work in August 1971, five months before conversion to expanded operations. During this period the supervisor became acquainted with all plant functions and machinery and also developed procedures that would be implemented under expanded plant operations. The addition of a plant supervisor has resulted in: 1) increased plant production, 2) more efficient use of man power, and 3) a remarkable improvement in plant cleanliness and appearance.

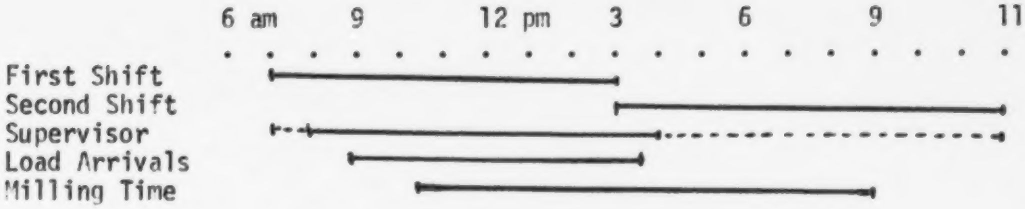
Daily Operation:

Table 10 shows the prescribed duty hours for each shift and the supervisor. Also included is the average time span for load arrivals and average mill operating time. **The average length of a milling day is 10.5 hours (10:30 a.m. to 9:00 p.m.).**

Table 10 indicates that first shift hours are from 7:00 a.m. to 3:00 p.m. and second shift hours from 3:00 p.m. to 11:00 p.m. The supervisor's hours are 8:00 a.m. to 4:00 p.m. Times of load arrivals vary each day of the week but on the average encompass the hours of 9:00 a.m. and 3:00 p.m. Mill start time is closely coordinated to load arrivals but generally averages 10:30 a.m. Mill stop time averages approximately 9:00 p.m.

Table 10

Hourly Breakdown of Average Day



Preventive Maintenance Program:

The hourly bar chart in Table 10 indicates a 3.5 hour peridd between arrival of first shift personnel and mill start time. This time is used for any necessary plant clean-up and also to conduct an extensive preventive maintenance program. The program consists of equipment inspections, minor repairs, and any hard facing that needs to be done.

Detailed inspections are performed on Mondays. At this time notes are taken as to what repairs or replacements **are** needed. The necessary work is then scheduled for completion during upcoming weeks. Necessary lubrication is also applied during Monday inspections. The mills are inspected and hammers tipped or replaced as necessary on a daily basis. Also, portions of the mill interior may be hard faced if needed.

Load Arrivals and Mill Start Times:

Packer trucks deposit their loads at the plant over a 6.5 hour period. However, the trucks usually arrive in bunches at three specific times during that period - middle morning, noon, and mid-afternoon. Thus it is not uncommon for ten or twelve trucks to be lined up at one time waiting to enter the plant. A union agreement does not allow packer crews to start at staggered times. Another factor which contributes to the problem is a somewhat odd plant floor design that will permit only two trucks to maneuver inside the plant at one time. This **problem** does not affect plant operations, but does lower packer crew efficiency. One benefit derived from the situation is that the front-end loader operator does not have a continuous supply of unprocessed refuse to stack or move, thus allowing him free time to perform other duties.

On an average day, 53 loads (190 tons) are handled at the plant, although as many as 72 loads (340 tons) per day have been deposited. These figures represent the entire city's collection crews and some private packers (3 to 6 loads per day). In 1972, approximately 46,000 tons were milled in the two-mill, two-shift operation at Madison. It is important to note here that all residential and light commercial refuse collected by city crews is now being milled. Bulky items, brush, and bundled newspapers are being collected separately andaare not milled. The bulky items and brush are landfilled separately, while newspapers are recycled.

Although it is not evident from the table, there is a definite relationship between first load arrivals and mill start times. The basis of good mill operation is continuous material flow throughout a day's operation. Thus, mill start times must be planned to avoid production stoppages due to a lack of material. The plant supervisor has made detailed investigations of load arrivals and mill start times and determined that a lag of 1 1/2 hours beyond the first load arrival will eliminate almost all production stoppages due to material shortages.

Overtime Requirements:

Overtime performed by plant personnel has been primarily a result of machine breakdowns; very few instances have occurred where milling requirements have been a direct cause of overtime. On the average, 15 man hours of overtime per week have been reported for the 7-man crews. Although not excessive, this time does appreciably add to process costs since it is nonproductive.

Mill Performance:

Mill performance is measured by a combination of operating time, down time, power consumption, and daily tons of refuse milled. In the design of the two-shift operation it was assumed that an average of 280 tons of refuse could be processed per 13 to 14 mill-hour day at a plant production rate of 20 to 22 tons per hour. During the first 6 months of 1972 an average of nearly 190 tons of refuse was processed per 10.4 mill-hour day at a plant production rate of nearly 18 tons per hour. These figures are somewhat short of design but are nevertheless satisfactory at this stage of operation.

Two causes were responsible for the difference in the design and actual figures. First was the fact that during the initial 3 months of operation, refuse generation was at its seasonal low. Second, mill downtime, near 2.8 hours per 10.4 hour operating day, was quite high. Efforts are underway to increase available tonnage by increasing the availability of privately collected refuse. A concentrated effort is being made by plant personnel to decrease the ration of down time to operating hours. More detailed data on plant performance is presented below.

Production Rates:

As stated previously, production rates are a ratio of tons processed and operating time. The rates are measured in tons per hour (TPH). Two rates are computed for the Madison operation. The first is named overall production rate and is computed considering machine down time in addition to actual operating time. The second - operational production rate - is computed using only actual operating time. The rates measure plant and machine efficiency, respectively.

During experimental runs of both the Gondard and Tollemache mills, operating and down times were recorded manually. It was felt that this method would not be adequate under full-scale operation. As a consequence simple strip chart recorders were installed to measure operating and down time for each mill. The recorders are equipped to record mill motor amperage on a continuous running time chart. Thus it is possible to determine machine time above certain loadings. At Madison, mill idle is the break point. All times above this are productive, all below are considered down

Since each mill has different rated capacities and the plant has no means to record tons milled by each machine separately, it is necessary to compute combined productive rates. Plant efficiency is computed by using the largest elapsed time recorded by either machine, the reasoning being that even if only one mill is operating the entire plant is functioning and this inefficiency should be reflected in plant production rates. Quite obviously in order to maximize plant production rates, simultaneous mill operation must also be maximized.

An even moee complicated method is used to compute machine production rates. Again since both machines have different rated capacities it is necessary to use an assumed combined design capacity. The values used are 8 TPH and 14 TPH for the Gondard and Tollemache mills respectively. The combined figure is then 22 TPH. Using each mill design capacity and operating time, ideal tonnages are computed, added, and then compared to actual total tonnage milled. The ratio of actual milled tons to ideal milled tons times the combined design capacity gives the figure which is designated machine production rate. As can be seen this figure is a numberical value dependent on the assumed mill design capacities and as such is not directly a real indication of how each machine is actually performing; but it has worked very well in depicting what production rates might be expected if no down time is experienced during daily operation.

Table 11 presents a compilation of 6 months of operating data for the plant and mills during 1972. Included in the table on a monthly basis are tons milled, plant operating time, overall and operational production, refuse moisture content, and production rate on a day dry-ton basis. Refuse moisture content as presented is computed on a refuse dry weight basis. Also included in this table are production figures forthe second half of 1972, following the evaluation period.

The data presented show a gradual increase in plant tonnage as the year progressed. The increase is due to seasonal variations in refuse generation. On a daily basis, tons processed averaged a low of 125 in January to a high of 254 during May. Operating time quite naturally also reflects this trend going from a low of 7.7 hrs. in January to a high of 13.1 hours in May. Down time increased with every month, peaking in April and May at 77 hrs. A ration of down time to operating time indicates that March had a high of 0.39 hours of down time for every hour of operation. This figure was decreased to 0.25 by June. Further decreases in down time are needed in order to increase plant production rates and overall operational efficiency. Optimum plant operation would be achieved when plant TPH is equal to machine TPH and this, of course, can only be achieved when down time is reduced to zero.

TABLE 11

Operational and Overall Production Rates (1972)

(Two-Mill, Two-Shift Operation)

	Tons Milled	Hours[1] Plant Time	Hours[2] Down Time	Overall[3] Rate (TPH)	Operational[4] Rate (TPH)	% Moisture Content	Dry Tons	Overall Rate (Dry TPH)
January	2663	161	26	16.51	17.93	23	2165	13.44
February	3334	205	39	16.28	17.93	23	2710	13.22
March	3440	208	74	16.51	20.00	25	2752	13.24
April	4236	235	77	18.04	21.98	29	3287	14.00
May	5126	262	77	19.57	22.86	40	3665	14.00
June	4518	232	57	19.48	22.24	38	3276	14.15
Overall for January-June 1972	23317	1303	350	17.90	20.63	31	17855	13.71
July*	2165	130	51	16.64	22.49			
August	4947	232	37	21.32	23.17			
September	4797	230	31	20.83	22.44			
October**	3040	163	26	18.61	20.16			
November	4840	243	29	19.91	21.74			
December	3483	197	39	17.72	19.23			
Overall for July-December 1972	23272	1195	213	19.47	21.72			
Overall for 1972	46589	2498	563	18.65	21.22			

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* Low production because density tests conducted at landfill diverted considerable unprocessed refuse.

**Low production because rotor was being changed on Tollemache mill.

1. Elapsed time from first mill start-up to last mill shut-down including milling plus down time.
2. Summation of hours down time for Gondard mill plus Tollemache mill.
3. Tons milled/hours milling plus down time.
4. Operating rate is defined by the following formula for a two mill facility, to take into account the different milling capacities for the two mills:

$$\frac{(22\text{ tons/hr}) \times \text{Tons Milled}}{(\text{Tollemache operating hours} \times 14\text{ tons/hr}) + (\text{Gondard operating hours} \times 8\text{ tons/hr})}$$

The data presented also show an increase in production rates from January to June. This is a result of improved plant operation and also an increase in refuse moisture content. Plant dry tons per hour (DTPH) illustrates this very well. The maximum variation from the overall figure of 13.71 DTPH is only 0.49 while on plant TPH the maximum variation is 2.5 A better illustration is shown in Figure 21. In the figure, plant TPH and plant DTPH are plotted versus time. Also plotted is refuse moisture content on a dry weight basis. Notice how plant TPH follows moisture content very closely while plant DTPH shows only a slight increase from March to April. This increase is more likely to be a result of improved plant operation.

Power Consumption - Mills Combined:

Mill power consumption is based on demand measured in kilowatts ((kw) and energy usage measured in kilowatt hours (kwh). Demand is related to instantaneous peak loadings and is not related to tons processed. Energy usage is based on machine running and to some extent on machine running and to some extent on machine loading; thus it can be related to tons as KWH/ton. With the advent of combined mill operation and with no means to record tonnage milled by each individual machine, KWH/ton will be discussed on a combined basis. Power usage was recorded by a 440-volt watt-hour meter installed on each mill during February 1972.

From Table 12 it is evident that the Gondard machine created more demand for power than the Tollemache mill in all months except June. It also should be stated that the Gondard mill used nearly as much energy as the Tollemache mill while only being rated at 58 percent the capacity of that mill. Previous individual mill evaluations back up these results. The Gondard mill was reported to consume power at the rate of 12.5 KWH/ton while the Tollemache mill used only 7.2 KWH/ton on the average. The combined overall KWH/ton of 7.19 is better than the everage of either machine on previous evaluations; but it should be stated that the data were collected in 1972 during a period which in the past has produced the lowers power consumption recorded during a year. On a dry-ton basis, the overall combined figure was 9.61 KWH dry-ton. No apparent relationship between moisture content and power consumption seems to exist as in the case of production rates.

Power Consumption - Mill Accessories Combined:

For this evaluation, mill accessories included all conveyors (feed and take away) and welding equipment, all of which operate from a 440-volt power source. The stationary compactor system will be considered later in this report. Power consumption for accessories was determined by taking the difference between the total 440-volt power usage and that used by both mills combined. Data obtained during this evaluation indicated that on the average accessory demand is only 7 percent of the total for both mills and that energy usage is 18 percent of the total energy usage for both mills. Thus mill accessories required approximately 1.29 KWH/ton and 1.34 KWH/dry-ton of electical energy.

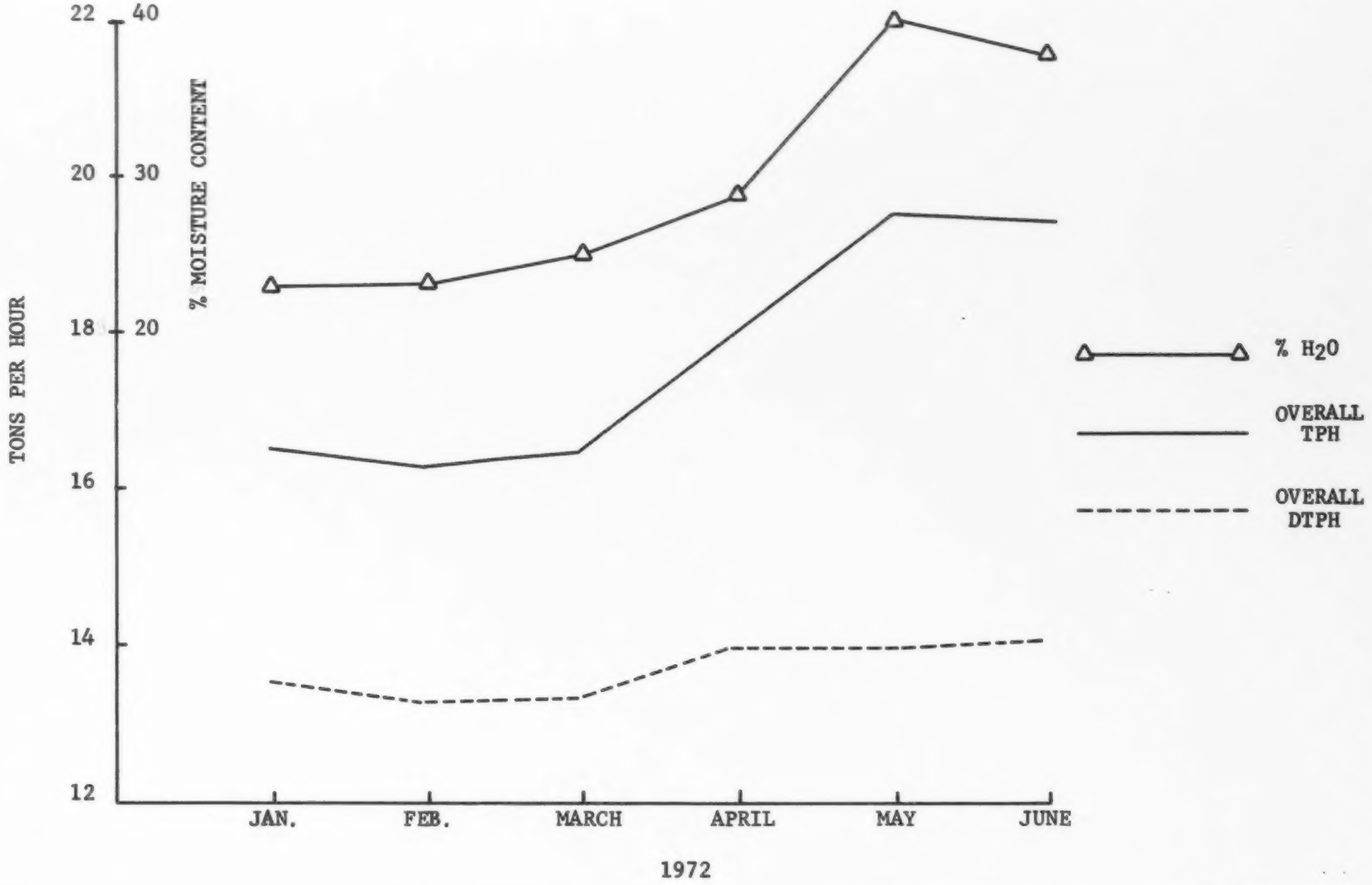


Figure 21. Comparison of Moisture Content and Overall Production Rates

The data in Table 11 also show an increase in production rates from January to June. Although this production rate increase reflects improving plant operation, it is more directly related to an increase in refuse moisture content. Figures showing the operational rates in terms of dry tons per hour (DTPH) illustrate this dramatically. The maximum variation from the overall figure of 13.71 DTPH is only 0.49, while the maximum variation in production rate (TPH) is 2.5.

Power usage (KWH) was recorded by a 440-volt watt-hour meter installed in February 1972 on each mill. These figures are shown in Table 12.

TABLE 12

Power Consumption - Mills Combined (1972)

	Demand (kw)		Combined Energy Usage (KWH)	KWH/Ton	KWH/Dry Ton
	Tollemache	Gondard			
March	131	138	31,770	9.28	11.56
April	125	134	31,157	7.38	9.47
May	116	121	31,950	6.23	8.40
June	120	116	29,730	6.60	9.07
Overall				7.19	9.61

Stationary Compactor and Transfer Trailer Performance:

With the simultaneous operation of both mills, an increase in loading on the stationary compactor system has occurred. The characteristics of the compactor trailer operation revised from those in Section III-B, are:

1) It takes only 45 to 60 min. to fill one 35 cu. yd. trailer.
2) The 35-cu.-yd. storage hopper now does not provide enough volume to allow milling to continue while normal trailer switching takes place. The mills in combined operation fill the bin in 2 to 5 min.
3) This system now gives one man an extra 25 to 40 min. for duties other than those related to milled refuse transportation.

Power Consumption:

A watt-hour meter was also installed on the power source to the stationary compactor in February 1972. Unfortunately, adequate data were not obtained until April. Table 13 contains a summary of power requirements for the compactor system.

Table 13

Power Consumption - Stationary Compactor (1972)

	Demand (KW)	Energy (KWH)	KWH/Ton	KWH/dry-ton
April	17.0	3428	0.81	1.04
May	15.5	3874	0.76	1.06
June	14.0	3265	0.72	1.00
Overall			0.76	1.03

It is evident that the compactor requires less than 10 percent of the power of the mills and their accessories. The overall value for the period of record was 0.76 KWH/ton. On a dry-ton basis the value increased to 1.03 KWH/dry-ton overall.

Operation Overview:

An overview of the first 6 months of operation on a two-shift basis has revealed that the plant has not been hampered too severely by breakdowns, scheduling problems, or labor deficiencies. At this period in the two-shift operation, it was unrealistic to assume that an average of 280 tons of refuse could be milled daily. As previously stated, this would require 13 to 14 hours at a combined plant production rate of 20 to 22 tons per hour. From the production data presented in Table 11 it is apparent that not during any of the months of record was a plant production rate of 20 TPH achieved. Even if the highest rate obtained during the period of record, 19.57 TPH, were to be maintained year around, it would require 14.3 hours of mill operation per day to process 280 tons. This would leave only 1.7 hours for clean-up and preventive maintenance, which would not be sufficient. Thus it is more likely that under the present system a 12 to 13 hour milling day, at an average 18 to 19 TPH, yielding nearly 230 tons per day, would be more realistic.

It also should be realized that this operation involves new personnel and operating characteristics. Thus it is fair to say that the system was not operating to its fullest potential. This is evidenced by the increased amount of down time experienced during the two-shift operation compared to down times experienced during single mill evaluations, as cited in other portions of this report. Therefore it is realistic to assume that mill production should increase to near 20 TPH on a yearly average combined with a 12 to 13 hour milling day; this would result in an average daily production of 240 tons or a yearly average of 60,000 to 65,000 tons.

OPERATING COSTS

Extensive cost data on all plant functions were collected from January 1 to June 30, 1972. Data collected will be presented under two main divisions, namely that of milling costs and that of compaction and final transportation. Cost data will be expressed in terms of total dollars expended and dollar cost per ton.

As stated previously it is important to realize the implications of expressing costs on a per-ton basis. While such a figure is a good indicator and presents a good means of comparison, it can be seriously affected by many uncontrollable factors such as: 1) the average moisture content of the refuse being processed, 2) refuse characteristics, 3) type of material - residential, commercial, or industrial, and 4) geographic location of the plant. Therefore the cost per ton as stated here can be viewed only as an indication of what was experienced at the Madison installation. Another reason why these figures cannot be expected to be generally applicable to other locations is the diversity of equipment used - most importantly, two vastly different mills. The data are presented to give an indication of how milling costs on a two shift, increased-tonnage basis compared to costs on a one-shift basis. Information on how costs are computed is presented in Appendices K, L, and M and should be consulted before attempts are made to interpret the costs presented in this report. A detailed section concerning cost projections for a milling operation, utilizing the Tollemache mill only, is presented in Section III-E of this report.

Milling Costs:

The total cost of the 6-month evaluation period will be discussed first. This will be followed by descriptions of all pertinent cost areas. Table 14 contains a very detailed breakdown of the expenditures and cost per ton for the period of record. As stated previously total tons milled during that period were 23,317.

The total 6-month expenditure for mill operation was $91,001 or $3.90 per ton. Notice that labor and depreciation account for $2.75, or 71 percent of that total. Thus it is imperative to efficient operation that the maximum tonnage of refuse be milled during the 16-hour working

Table 14

Milling Costs For Two-Mill, Two-Shift Operation (January through June 1972)

	Total Cost	Cost/Ton*
Labor	$44,684	$1.912
Depreciation	19,570	0.838
Replacement Parts	8,097	0.346
Power	4,382	0.188
Hammers and Shafts	3,786	0.162
Heat-Gas	2,391	0.102
Supplies	2,196	0.094
Lighting	2,023	0.087
Front-End Loader Maintenance	1,653	0.071
Welding Rod	1,128	0.048
Contracted Repairs	1,047	0.045
Water and Sewer	44	0.002
Totals	$91,001	$3.895

* Based on 23,317 tons milled

day. If plant production could be increased from the current rate of 46,000 tons per year to a feasible 60,000 tons per year the total cost of milling could be reduced 15 percent to near $3.29 per ton. This is true because labor and depreciation are relatively fixed dollar costs that are not directly dependent on tons milled as are parts, hammers, etc.

The final figure of $3.90 per ton as presented in Table 14 represents a sizable reduction from the earlier stated costs for experimental runs of both the Gondard and Tollemache systems separately. The figure is 48 percent lower than that actually experienced during the Gondard evaluations of 1967, 1968, and 1969. It is also 19 percent lower than the average figure obtained during the Tollemache evaluations of 1970 and 1971. The reduction is the result of betterssupervision and the 125 percent average daily increase in tonnage milled over that of the single-shift operations.

Labor:

Total milling labor costs as charged to the plant during the 6 months of record are shown in Table 15.

The total labor cost, $44,684, as shown in the table is based on the average annual hourly wage including fringe benefits as computed in Appendix K. Average annual hourly wage for plant personnel is $6.993 and for the plant supervisor $6.254. The supervisor's rate is lower because he does not have longevity nor are there sick leave and vacation substitutes provided as with regular plant personnel. The final figure is also based only on regular hours worked. The reason no overtime hours are used is that they are considered a fringe benefit and as such are used in computing the average annual hourly wage.

Table 15

Labor Costs - Two-Mill, Two-Shift Operation
(January through June 1972)

	Regular Hours	Cost*	Cost/Ton**
Plant Personnel	5460	$38,180	$1.634
Supervision	1040	6,504	0.278
Total	6500	$44,684	$1,912

*Includes all fringe benefits (See Appendix K.)
**Based on 23,317 tons milled.

The working day of plant personnel can be divided into three main categories: 1) mill operation, 2) repair maintenance, and 3) hammer maintenance. Mill operation consists of all functions related to daily milling such as mill control, front-end loader operation, clean-up, etc. Repair maintenance is exactly what the name implies, and hammer maintenance consists of time devoted to hammer tipping and changes. The breakdown of milling labor costs is shown in Table 16. No differentiation is made between the times devoted to the Gondard or Tollemache system individually because sufficient data of this sort appear in other portions of this report.

Table 16

Breakdown of Labor Costs
Two-Mill, Two-Shift Operation
(January through June 1972)

	Man-Hours			
	Total	Per Week	Cost*	Cost/Ton**
Mill Operation	3969	152.6	$27,754	$1.188
Repair Maintenance	850	32.7	5,944	0.254
Hammer Maintenance	641	24.7	4,482	0.192
Subtotal	5460	210.0	$38,180	$1.634
Supervision	1040	40.0	6,504	0.278
Total	6500	250.0	$44,684	$1.912

*Includes all fringe benefits
**Based on 23,317 tons milled.

The data clearly indicate that almost 73 percent of the total labor cost, not including supervisor, is a result of mill operations, while only 15 percent and 12 percent is the result of repair and hammer maintenance, respectively.

Depreciation:

Complete depreciation data for the milling system are presented in Appendix **L.** Based on the data available, the total cost for the entire 6-month period was $19,570. On a per-ton basis the figure is $0.838.

Power:

Power costs for the two mills combined are presented in Table 17 on a monthly basis. Table 18 contains data on mill accessories. A detailed breakdown of current power and utility rates is available in Appendix **M.** Demand or energy usage has been discussed earlier in this report.

Table 17

Power Costs, Mills, Two-Mill, Two-Shift Operation
(January through June 1972)

	Demand Cost	Energy Cost	Total Cost	Cost/Ton*
January	$ 341	$ 257	$ 598	$0.225
February	341	311	652	0.195
March	341	332	673	0.196
April	341	329	670	0.158
May	341	330	671	0.131
June	341	321	662	0.146
Overall	$2,046	$1,880	$3,926	$0.168

Table 18

Power Costs, Mill Accessories, Two-Mill, Two-Shift Operation
(January through June 1972)

	Demand Cost	Energy Cost	Total Cost	Cost/Ton*January
	$ 19	$ 47	$ 66	$ 0.025
February	19	56	75	0.023
March	19	60	79	0.023
April	19	60	79	0.019
May	19	61	80	0.015
June	19	58	77	0.017
Overall	$114	$342	$456	$ 0.020

*Based on 23,317 tons milled.

In both tables demand is constant and in the case of the mills the demand charge costs more than the energy used. This is an important factor in the overall power cost, as an increase in tonnage milled will decrease the total cost per ton. For example, during the Tollemache shakedowns, power averaged $0.24 per ton at an average rate of 70 tons of refuse milled per day. Power costs for the Gondard shakedowns averaged about $0.28 per ton back in 1968, at much lower rates, on the average of 46 tons of refuse milled per day. During 1972 the combined mill operation consumed power at the cost of $0.168 per ton, or a 53 percent reduction over the single-mill operation. The reason for the decrease is that 187 tons of refuse were processed per day in 1972.

220-Volt Service - Lighting:

Lighting and other small services are supplied by 220 volt service. Table 19 contains monthly 220-volt service costs and electricity used.

Table 19

Lighting Costs, Two-Mill, Two-Shift Operation
(January through June 1972)

	Demand (kw)	Energy (KWH)	Demand Cost	Energy Cost	Total Cost	Cost/Ton*
January	38.6	18,788	$58	$319	$377	$0.141
February	40.0	17,088	61	293	354	0.106
March	40.0	19,286	61	326	387	0.113
April	40.0	14,734	61	258	319	0.075
May	40.0	12,772	61	228	289	0.056
June	40.0	13,294	61	236	297	0.066
Overall			$363	$1,660	$2,023	$0.086

*Based on 23,317 tons milled.

Heat - Gas:

The plant is heated by radiant natural gas heaters. Table 20 contains a monthly breakdown of heating costs. The total expenditure reflects three months of winter heating bills and three months of much lower spring bills. Past experience has shown that heating costs have gone almost to zero from June through September.

Water and Sewer:

Total water usage equaled 6510 cu. ft. Cost of this water equaled $21.00. Sewer charges are 140 percent of the total water cost. Thus the water and sewer bill for 6 months equalled $44.45, or $0.002 per ton.

Table 20

Plant Heating Costs, Two-Mill, Two-Shift Operation
(January through June 1972)

	Usage 100 Cu. Ft. Gas	Cost	Cost/Ton*
January	8,679	$ 823	$ 0.309
February	8,297	788	0.262
March	5,124	468	0.136
April	1,983	194	0.046
May	618	63	0.012
June	540	55	0.012
Overall		$2,391	$ 0.102

*Based on 23,317 tons milled.

Supplies - Hammer Maintenance Program:

Items such as hammers, hammer shafts, and welding rods constitute supplies used in the hammer maintenance program. Table 21 contains all pertinent data in respect to number of each item used and resultant expenditure.

Table 21

Supply Costs, Hammer Maintenance, Two-Mill, Two-Shift Operation
(January through June 1972)

	Used	Unit Cost	Total Cost	Cost/Ton*
Hammers	1000	$ 3.27	$3,270	$0.140
Shafts	43	12.00	516	0.022
Welding Rod (lbs.)	600	1.88	1,128	0.048
Overall			$4,914	$0.210

*Based on 23,317 tons milled.

The total cost of hammer maintenance supplies was $4,914, or the fourth largest expenditure in respect to plant operation. It would be expected that the $0.21 per ton would remain relatively constant if changes in daily tonnage milled were to occur.

Replacement Parts:

As indicated in Table 14, cost of replacement parts was over $8,000 $0.35 per ton, and is the third most expensive item on the list. Parts, replaced during the period of record were mill grates (Gondard) and wear plates (Tollemache) as well as conveyor belting - all of which are very expensive items. A set of Tollemache liners, which last approximately 6 months, costs nearly $1,300. Gondard grates also lasting 6 months cost nearly $800 per set. Other parts such as small motors, conveyor slats, bearing, etc. make up the remainder of the expenditure in this area.

Other Expenses:

Other expenses include miscellaneous supplies, contracted repairs, and front-end loader maintenance. Supplies consist of janitorial requirements, office materials, grease and oils, etc. The total expenditure for supplies, $2,196, costs almost $0.10 per ton. Contracted repairs include all labor and material charges. for repairs made by outside concerns. The total cost, $1,047, is less than $0.05 per ton. Front-end loader maintenance is dependent on the hours of vehicle use. The city garage charges $4.27 per hour to cover vehicle maintenance such as oil, minor repairs, grease, etc.

Stationary Compaction and Haul Costs:

Expenses for compaction and hauling include labor, depreciation, power, and equipment maintenance. Not included are very small expenses due to heat, lighting, and water which are grouped under milling costs. Table 22 gives a complete listing of all expenses attributed to final handling of the milled material.

Table 22

Stationary Compaction and Haul Costs, Two-Mill, Two Shift Operation
(January through June 1972)

	Cost	Cost/Ton*
Labor	$5,216	$0.223
Depreciation	4,380	0.188
Compactor Maintenance	753	0.032
Haul-Vehicle Maintenance	597	0.025
Power	334	0.014
Overall	$11,280	$0.482

*Based on 23,317 tons milled.

Labor expenses, as was the case with milling costs, constitute the largest expenditure. A total of 780 hours, or 30 man hours per week, was spent in transporting milled material to the landfill. (Round trip is less than 1/2 mile.) Depreciation charges are computed in Appendix L and include the compactor and all haul equipment. Vehicle maintenance is computed on a per-mile charge. Tractors are charged at a rate of $0.20 per mile and transfer trailers at the rate of $0.25 per mile. Charges cover all oils, grease, and minor repairs.

Power usage was presented in Table 13 and need not be stated again. Table 22 indicates that the total power cost is almost insignificant at $0.014 per ton. Compactor maintenance at $0.032 per ton consists of labor and parts for all repairs to the compactor. As the figures show, the compactor is not prone to breakdowns.

III-D - Operational Cost Of Landfilling Milled Refuse

The original Gondard project investigations included an initial examination of the operational costs of landfilling milled refuse. These data were limited to the extent that the evaluations were made on the basis of landfilling only 40 to 60 tons of milled refuse per day.

With the advent of the double shift operation and the subsequent milling of an average of more than 180 tons of refuse per day, better data on landfillings costs became available. As a result, extensive records of landfill costs were kept during the period of January 1 to June 30, 1972. These data have been reduced and are presented in tht following portions of the report.

Cost data will be presented in two forms. The first will be a detailed explanation of expenses incurred and second will be a comparison of two separate landfill operations--one milled, the second unprocessed; both are operated by the City of Madison.

LANDFILLING COSTS USING MILLED UNCOVERED REFUSE

Located only one-quarter mile from Madison's refuse reduction plant is the Olin Avenue landfill site. Originally a swamp, the area was first used as an open burning dump in the late 1940's. During the early 1960's the area was converted to a sanitary landfill. In 1966 the solid waste reduction plant was installed on a small portion of city land adjacent to the fill. From 1966 until 1971 the landfill site was used as a test area for comparing the degradation of milled uncovered refuse and unppocessed covered refuse. Normal sanitary landfilling also took place at the site. In mid-1971 the area was completely converted to a landfill for milled refuse to which no daily cover was applied. At this time only one piece of machinery was regularly used at the site.

When the conversion to a two-shift operation was completed in January 1972, no drastic changes in the operation took place. It was felt that the Trash Pak on the site was adequate to handle the increased volume of material. To date this has been true. There is no problem in handling the 180-ton-per-day average of milled refuse, and indications are that the present one-machine operation could handle 300 tons on a daily basis. No attempt will be made here to describe the physical aspects of landfilling milled solid wastes, as adequate data exist in other portions of this report.

Total Operating Cost:

The total cost of operating the Olin Avenue landfill includes expenditures for labor, supervision, depreciation, cleanup, equipment maintenance, etc. Table 23 contains all data collected in respect to expenditures at the Olin Avenue milled refuse site from January 1 to June 30, 1972. The data will be followed by explanations of each category used in the table. No charge for land is included because the land has been owned by the City for an extended period of time. It should be noted that land costs are regularly omitted from similar reports. Also not included is a cost for cover dirt (none was used) because the idea behind milled refuse landfill operations is the elimination of daily cover dirt requirements, although it is recognized that cover should be applied at certain times throughout the year depending on local conditions.

TABLE 23

Landfill Costs Using Milled Uncovered Refuse (January through June 1972)

	Cost	Cost/Ton**
Wages*		
Compaction	$ 7,290	$ 0.312
Supervision	2,143	0.092
Cleanup	6,363	0.272
Auxiliary Operation	223	0.010
Subtotal	$16,019	$ 0.686
Equipment		
Permanent	$ 4,825	$ 0.686
Auxiliary	717	0.030
Depreciation (Permanent)	818	0.035
Subtotal	$ 6,360	$ 0.272
Materials - Area Improvement		
Stone	$ 435	$ 0.019
Road Oil	420	0.018
Subtotal	$ 855	$ 0.037
Total	$23,234	$ 0.994

*Includes all fringe benefits.
**Based on 23,317 tons milled.

The 6-month landfill operation cost the city $23,234, while 23,317 tons of refuse were disposed. This represents a per-ton expenditure of only $0.994.

Wages

By far the largest cost of the landfill operation was that for labor. The fill is manned by one full-time compactor operator. The operator averages 6 hours on the fill and 2 hours for equipment maintenance. Total overtime for the 6-months period **was 20** hours--less than one hour per week. The operator works from 7:30 a.m. until 4:00 p.m. All material processed after 4:00 p.m. is stockpiled on the fill to be pushed and compacted **the** following morning.

There were no difficulties in handling the average daily loading of over 180 tons. There is even a belief that an average of 300 tons per day could be handled routinely. This is possible because it takes only 15 to 20 minutes to spread and compact a load of milled material. This represents a minimum of 3 loads per hour that could be handled. At 6 machine operating hours per day and an average of 15 tons of milled material per trailer load, a minimum of 270 tons of a maximum of 360 tons of milled material per day could be placed and compacted. At present there is a 45 to 60 minute lag between each load of milled refuse; thus the operator has nearly 30 minutes per hour when no milled refuse is available for compaction. This time is used in further compacting in-place refuse, but could be used to handle more material as mentioned above. Another fact that should be mentioned is that it takes only about one hour to spread and compact the 45 to 100 tons of milled refuse left each night after the operator leaves for the day.

The second largest labor expenditure was for area cleanup. Cleanup consists of paper pickup, grass cutting, etc. Cleanup averaged 184 man hours per month.

Supervision is provided by Madison Street Department foremen. The supervisor averages about 2 hours per day at the site.

An auxiliary operator spent 32 hours at the landfill site during the six-months period on repair to the access road.

Equipment

Permanent equipment includes a steel-wheeled compactor, which has proven very effective on milled material. It is operated between 5 and 7 hours per day. Charges are based on hours used. The City garage sets the hourly rate at $6.25. Depreciation is at the rate of $1,636 per year. Auxiliary equipment was used only for road improvement and site cleanup. No depreciation is charged for auxiliary equipment because of its limited use.

Materials - Area Improvement

Stone and oil are used on site access road improvements. The stone allows better wet-weather operation. The road oil keeps dust down in the summer dry periods.

COST COMPARISON - MILLED AND UNPROCESSED REFUSE

Below is a cost comparison of two Madison landfills. The first is the Olin Avenue landfill which utilizes milled uncovered refuse. The second is the Truax landfill which uses unprocessed refuse and operates under strict sanitary landfill conditions and uses liberal amounts of cover dirt. For this comparison it is assumed that the cover dirt used at Truax landfill is obtained free; although this is not always the case. Costs for excavating and hauling the dirt are included. Table 24 contains the data obtained from both operations on a per-ton basis. The Truax operation handled about two times the volume of material that was handled at the Olin Avenue site during the period of record, January through June of 1972.

The data as presented in Table 24 reveal that the City of Madison expends, on a per-ton basis, over three times the amount of money to landfill unprocessed refuse as it spends to landfill milled refuse. A further breakdown of the data shows that the City spends 2.8 times more money on wages and 3.6 times more money on equipment for conventional sanitary landfilling versus landfilling of milled refuse. It should be noted that the substantially higher cost of conventional landfilling as experienced in Madison is primarily due to the handling of cover dirt.

Table 24

Cost Comparison -
Milled Versus Unprocessed Refuse Landfills
(January through June 1972)

	Olin $/Ton	Truax $/Ton
Wages*		
Compaction	$0.312	$0.449
Supervision	0.092	0.229
Caretakers	-	0.374
Paper pickup	0.272	0.222
Loading (dirt)	-	0.182
Hauling (dirt)	-	0.335
Road repair	0.010	0.010
Scale operation	-	0.121
Subtotal	$0.686	$1.922
Equipment		
Compaction	$0.206	$1.922
Loading (dirt)	-	0.209
Hauling (dirt)	-	0.211
Paper pickup	0.020	0.015
Road repair	0.010	0.008
Misc. maintenance charges	-	0.076
Depreciation	0.035	0.105
Subtotal	$0.271	$1.073
Materials - Area Improvement		
Stone	$0.019	-
Road Oil	0.018	-
Subtotal	$0.037	-
Total	$0.994	$2.995

*Includes all fringe benefits

IV. CHARACTERISTICS OF MILLED REFUSE

IV-A - Particle Size and Density

This section discusses a study of particle sizes of milled municipal refuse as well as the results of compressibility tests on milled and unprocessed municipal refuse.

Sieving was found to be a suitable method for determining the particle size distribution of milled refuse. It was found that 80 to 90 percent of the particles on a dry weight basis passed through a 2-in. screen, and 15 to 30 percent passed through a 0.2-in. screen. The study also showed that refuse shredded with either the Gondard or Tollemache hammer mills, as operated in Madison, has approximately the same particle size distribution. Increased moisture content of refuse was found to result in a more finely ground product, whereas an increase in hammer wear was found to result in a more coarsely ground product, in the case of the Tollemache mill.

The compressibility tests on milled and unprocessed refuse showed densities approaching asymptotic values with increasing pressure. The densities of all test samples increased when vibrations were applied during compression; the increased densities varied directly with the amplitude of the vibrations. The resulting densities ranged from 1,510 (no vibrations) to 1,750 lbs./cu.yd. (with vibrations) for milled refuse at 80 psi pressure and 13,05 to 1,495 lbs./cu.yd. for unprocessed refuse at the same pressure. At the pressure and level of vibrations comparable to landfills compacted with a D-7 Caterpillar tractor, the density of milled refuse was 950 lbs./cu.yd. and that of similar but unprocessed refuse was 660 lbs./cu.yd.

Tests showed that the reduction in density due to springback after the pressure was released was about the same for both milled and unprocessed refuse--about 22 percent. A reduction in density of about 4.3 percent in the case of milled refuse and 9.1 percent in the case of unprocessed refuse samples was measured as a result of bridging along the sides of the container used in this study.

PARTICLE SIZE

EXPERIMENTAL PROCEDURE

Several possible techniques for determining particle size distribution in milled refuse were evaluated in preliminary tests, including direct measurement, sedimentation, and sieving. For this study, sieving was selected. Hand sieving, instead of mechanical shaking, was used to provide the variety of motions necessary to get milled refuse particles through the sieves.

Thirteen sieves of different mesh sizes (Table 25) were used for particle size analysis of milled refuse. A bottom pan was used to collect the sample passing through the finest screen, while a top lid contained the sample on the coarsest screen while shaking.

About 200 gms. of milled refuse were taken from a freshly collected refuse sample of about 7 lbs. It was spread in two glass pans and covered with aluminum foil. While drying, water vapor escaped through holes in the foil. The drying lasted from 18 to 24 hrs. in an oven with forced air circulation, at 100° C. After drying, the sample was cooled for 1 hr. in a large desiccator. Approximately 60 to 100 gms. of dry sample was then taken and weighed accurately to 0.1 gms.

The accurately weighed sample was used for sieving analysis. The sample was put on a 2-in. wire mesh sieve with a pan below and a lid on top. The particles passing through the mesh during shaking were collected in the pan. The weight of particles passing through the first sieve was recorded.

Particles passing through the 2-in. sieve were next placed on the 1-in. sieve and the shaking procedure repeated. This process was continued for each sieve in sequence. The percent of solids retained and passed through each sieve was calculated, based on the original dry weight of the sample.

Another possible method of analyzing particle size of milled refuse is direct measurement with a ruler. To compare the two methods, and to check the reliability of the sieving procedure, a 100-gm. sample of dry milled refuse was taken and analyzed by sieving. Then another sample was taken from the same source and analyzed by measuring individual particle size with a ruler.

TABLE 25

Standard Sieves

Sr. No.	U.S. Standard	Size of Mesh (inch)	Size of Mesh (mm)
1	2"	2"	50.8
2	1"	1"	25.4
3	½"	½"	12.7
4	U.S. 3	0.263"	6.68
5	U.S. 4	0.185"	4.7
6	U.S. 6	0.131"	3.34
7	U.S. 8	0.093"	2.362
8	U.S. 12	0.065"	1.650
9	U.S. 16	0.046"	1.242
10	U.S. 20	0.0328"	0.833
11	U.S. 50	0.0116"	0.295
12	U.S. 100	0.0059"	0.149
13	U.S. 120	0.0049"	0.124

The sample for direct measurement consisted of about 40 gms. of dried milled refuse. This sample was weighed accurately and placed on a large piece of paper. The largest dimension of each particle was measured with a ruler. Particles of similar size were kept in separate piles which were later weighed to calculate the percentage of that size, based on the original dry weight of the sample.

Figure 22 shows the results plotted as the size of mesh on a log scale vs. the percentage finer than the size shown on the ordinate. This figure shows that 97 percent of the particles were finer than 5 in. according to direct measurement, but finer than 2 in. according to the sieving test. Obviously, some particles larger than a given mesh size can pass through a screen along with smaller particles.

The curves become almost identical for the particles less than about 0.5 in., so the error in sieving appears most striking among the large particles. Although it is probably the only truly accurate method of determining particle sizes, the direct measurement method is time consuming. Therefore, even though these data showed some discrepancy between the two methods, sieving was the method chosen for the remainder of this study.

SPECIFIC TEST PROCEDURES, RESULTS, AND DISCUSSION

Moisture Content vs. Grinding:

The effect of moisture content on the particle size of milled refuse was determined by changing the moisture content of refuse during a special test sequence. On November 8, 1971, unprocessed municipal refuse taken from a huge pile was divided into three piles, each weighing approximately 500 lbs. A front-end loader was first weighed with the bucket empty and then filled with refuse. After weighing, the piles were designated A, B, and C.

Pile 'A' contained 560 lbs. of refuse, and no water was added to it. Pile 'B' contained 460 lbs. of refuse, and approximately 69 lbs. (31.4 liters) of water was sprinkled on the surface, while mixing with shovels, to increase the moisture content. Pile 'C' contained 480 lbs. of refuse and approximately 144 lbs. (65.5 liters) of water was applied as above. Each pile was mixed again, and then covered with a large polyethylene sheet to minimize loss of water during storage overnight.

The following morning each pile was mixed again before being ground. Refuse from pile 'A' was dumped into the feed bin and grinding was carried out with the Tollemache mill. Three samples, each containing about 5 to 7 lbs., were collected in separate bags, tied securely, and labeled.

A similar procedure was carried out with pile 'B' and 'C'. Care was taken while milling not to mix the sample from one pile with that of another. All bags were carried to the laboratory for analysis. Each sample was analyzed for moisture content and particle size. To determine moisture content, the refuse was placed in glass pans, spread evenly, and covered with aluminum foil. The pans were dried to constant weight at 100° C. (usually overnight), cooled in a desiccator, and again weighed accurately.

$$\text{Percent Moisture Content} = \frac{\text{Loss in wt.} \times 100}{\text{Dry wt.}}$$

Results and Discussion:

The samples of milled refuse from the three piles had a moisture content of 46.3, 66.2, and 91.5 percent on a dry weight basis, respectively. As the piles contained the refuse of November 8 only, the average composition of refuse in each pile could be expected to be similar. Also, since all three piles were ground within 2 hrs., under similar operating conditions, it was expected that there would be no effect on particle size due to hammer wear or feeding rate variations. Thus, by keeping all controllable conditions similar, the only variable affecting particle size could be expected to be the moisture content of the refuse. Figure 23 shows the particle size distribution curves following triplicate analyses.

A statistical analysis led to the conclusion that the moisture content of refuse may be expected to affect the particle sizes of refuse as milled with the Tollemache mill, with increasing moisture improving the grinding. This conclusion is true for the refuse under study and only for particle sizes larger than 0.2 in. For smaller particles, the moisture content has little effect on the particle size. This may be expected as particles of this range include dirt, glass, ceramics, etc., on which moisture content would have little or no effect.

Hammer Wear vs. Grinding:

Hammer wear is thought to affect the particle size of milled refuse. To determine this effect on particle size distribution of milled refuse, the procedure outlined below was adopted.

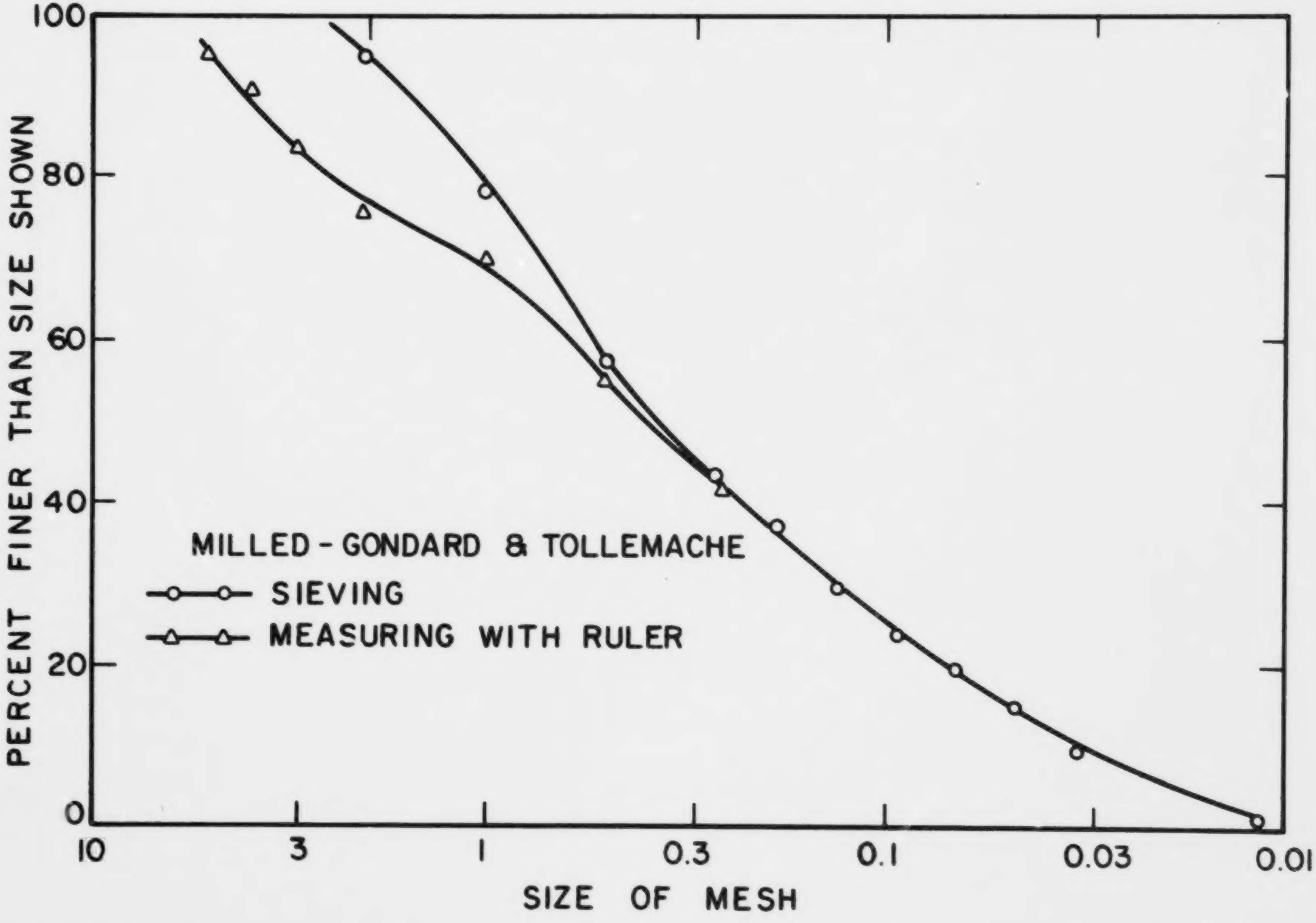


Figure 22. Particle Size Distribution Obtained by Sieving Compared to That Obtained With A Ruler

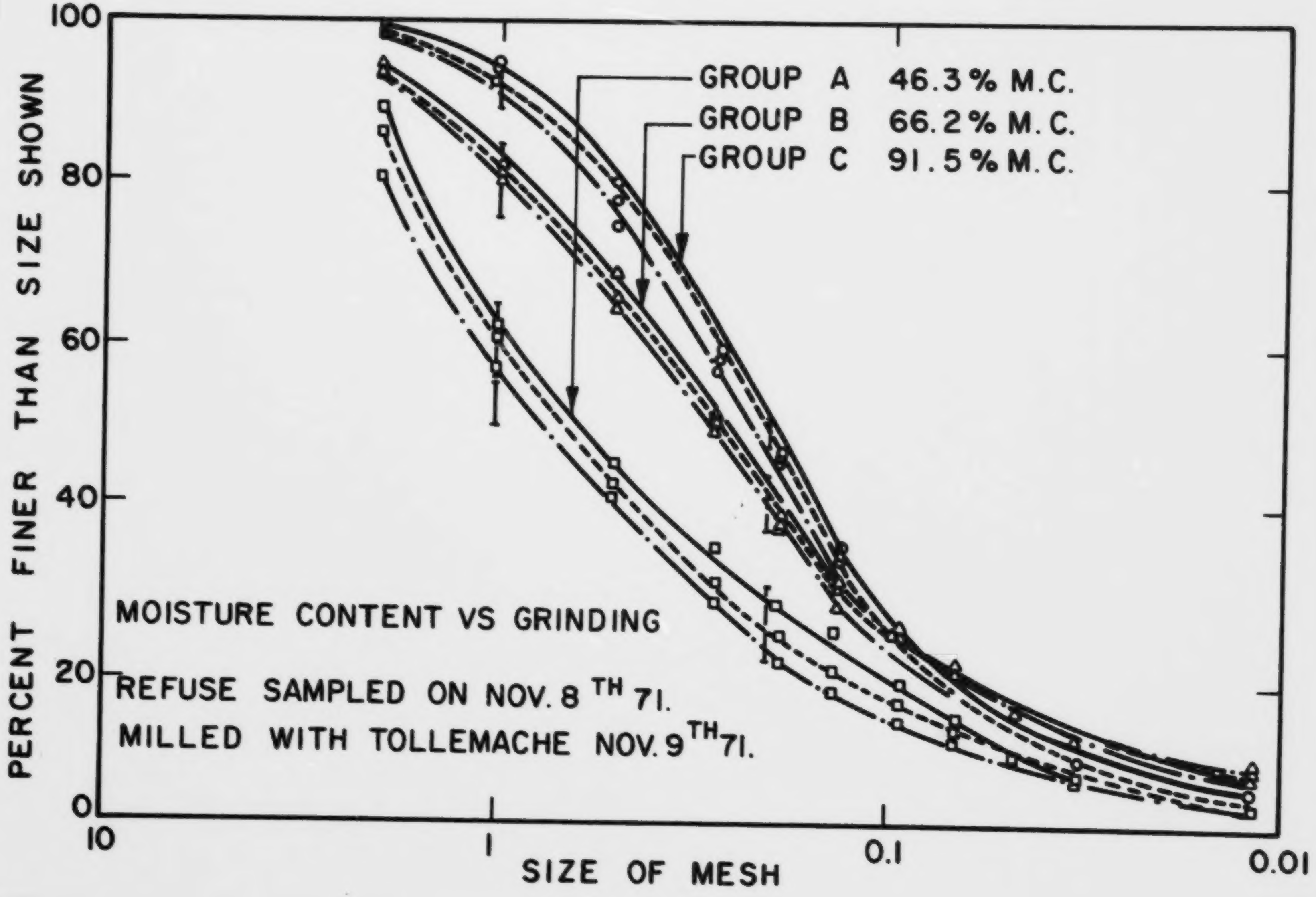


Figure 23. Particle Size Distributions Obtained at Different Refuse Moisture Contents

Three samples of refuse shredded with the Tollemache mill were collected every day over a 9-day test period. The samples were collected after the first truckload of refuse milled each day, and the date and number of tons of refuse milled since the last samples were taken were recorded. Each sample, weighing about 7 lbs., was collected in a plastic bag which was tied securely and labeled. Duplicate analyses were carried out on each sample to determine moisture content. Table 26 below shows the dates the sample was collected, the number of tons milled since the last hammer change, and the moisture content.

The sieving technique described previously was used to determine the particle size distribution of each sample.

TABLE 26

Dates of Particle Size Tests

	Date (1972)	Tons Milled Since Last Hammer Set Replacement	Moisture Content
Old hammers	March 21		24.0
New hammers	March 22	0	30.4
	March 23	107	27.6
	March 24	210	24.4
	March 27	323	25.0
	March 28	435	18.97
New hammers	April 7	0	32.9
	April 10	70	23.7
	April 11	210	18.1
	April 12	326	24.0

Results and Discussion:

Figures 24 and 25 show the resulting particle size distributions. It is clear from the distributions that the older hammers did produce a coarser product. It is interesting to note that in the first 2 to 3 days after a new set of hammers was installed, there was the most pronounced change in particle size distribution whereas after milling about 300 tons of refuse, there was not such a pronounced change in particle sizes.

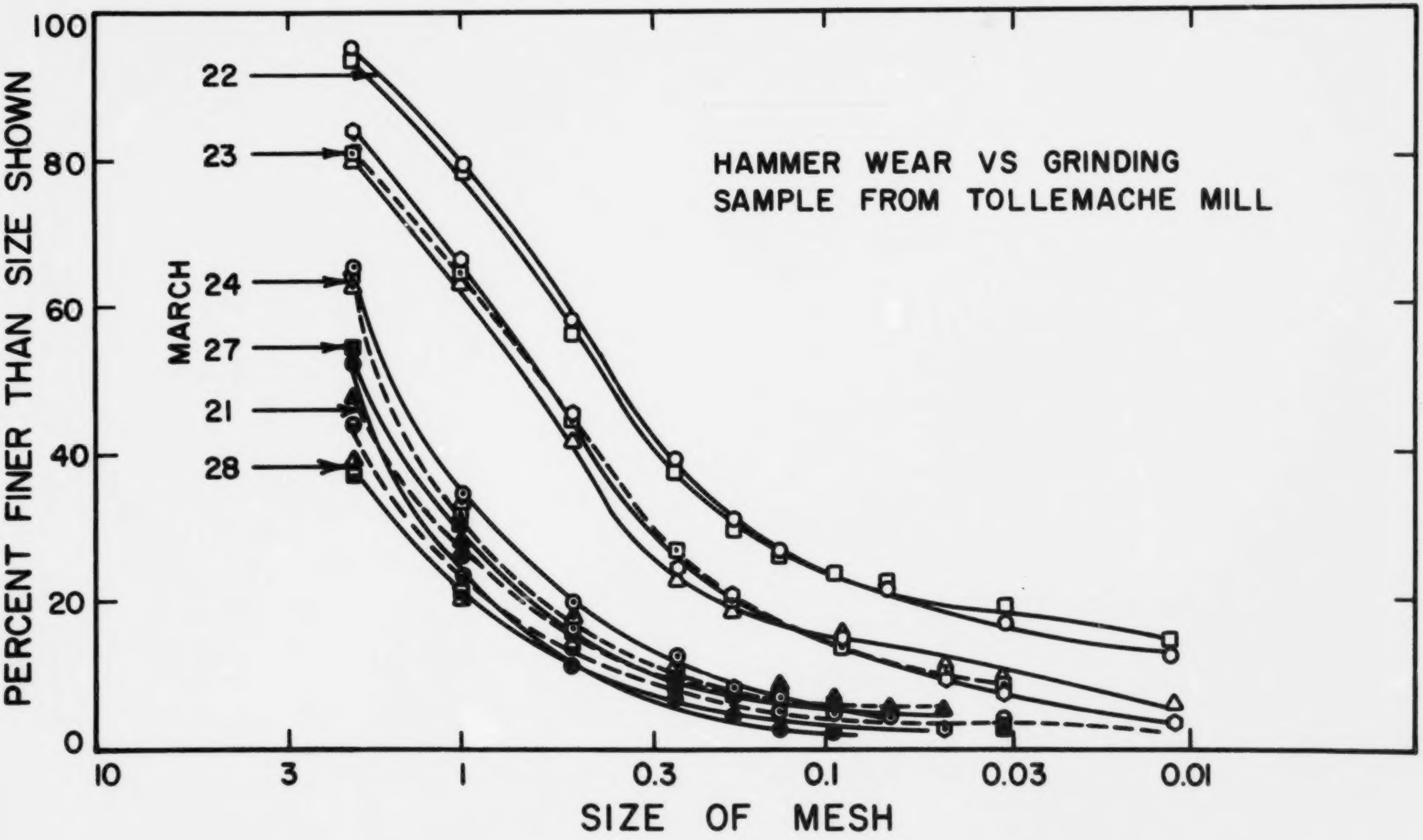


Figure 24. Apparent Effect of Hammer Wear on Particle Size Distribution

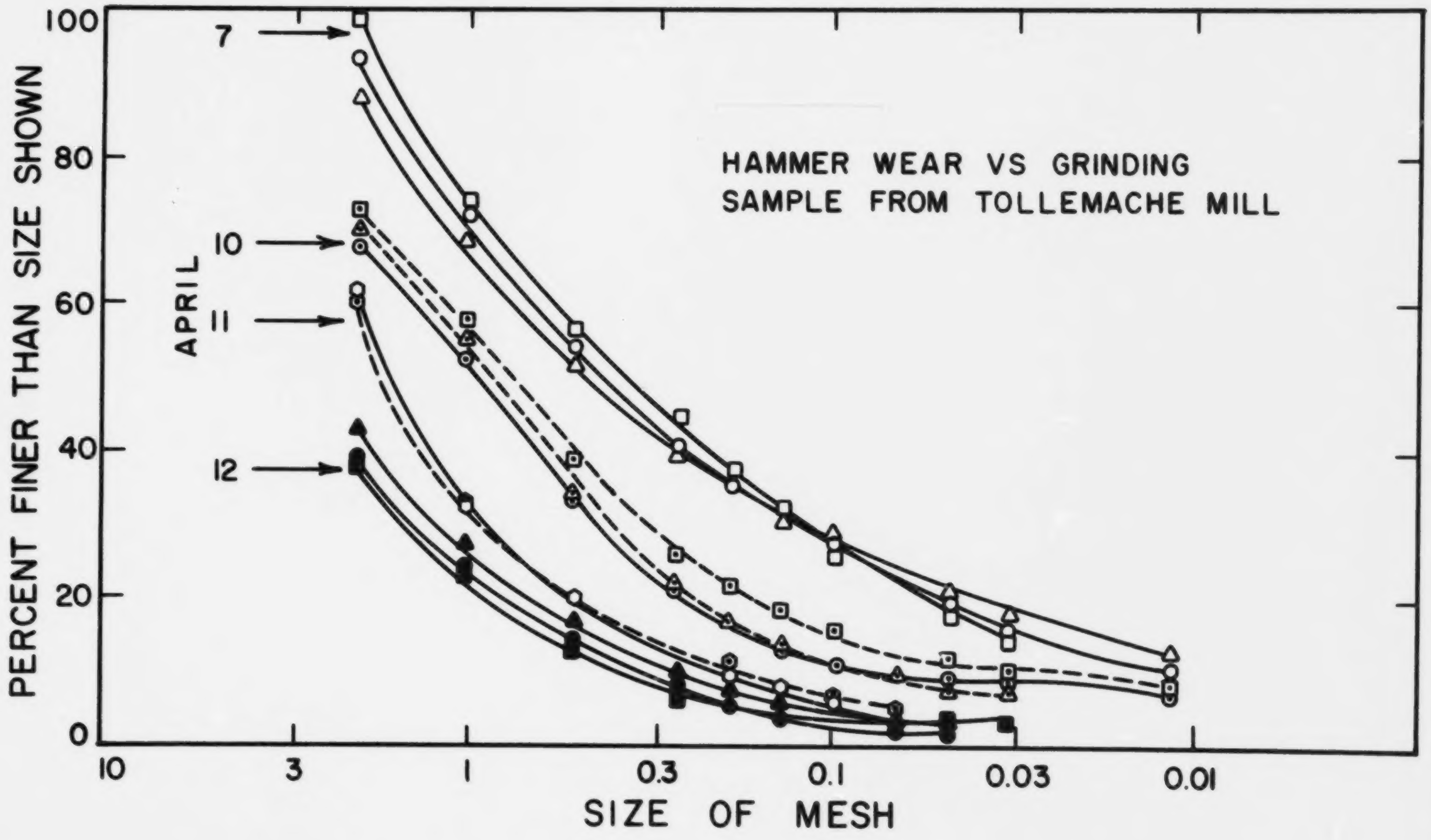


Figure 25. Apparent Effect of Hammer Wear on Particle Size Distribution

Particle Size Changes During Routine Milling:

To study the changes in the particle size distributions of refuse milled with Gondard and Tollemache mills during normal mill operations, samples were collected over approximately 1 yr. The samples were analyzed for moisture content and particle sizes. Some samples were unavailable during certain periods because one mill or the other was not in use. Since the samples were collected over a period of close to 1 yr., they may be expected to reflect all factors affecting particle size, such as moisture content, hammer wear, refuse composition, mill operation, etc. Samples taken include:

a. milled refuse from the Gondard mill only;

b. milled refuse from the Tollemache mill only;

c. milled refuse samples from both the Gondard and Tollemache mills.

The combined sample from both mills consists of approximately 71 percent from the Tollemache mill and 29 percent from the Gondard mill.

Results and Discussion:

Figures 26, 27, and 28 show the particle size distribution curves for the samples described above. Moisture content was also determined for each sample and is indicated in brackets on the plots. Only particle size distributions and moisture contents of the samples were determined. It is seen that factors other than moisture content were affecting the particle sizes. This effect is likely due to other factors, of which hammer wear is one described previously. However, these distribution curves can be compared with each other, assuming that the effects of refuse composition, mill operation, etc. are averaged out. Thus, the fineness of grind can be compared for the two mills, and the change in particle sizes over the year, for whatever reasons, can be observed.

It was found that the Gondard mill with a 5-in. grate produced approximately the same particle sizes as those produced by the Tollemache mill over the period in question.

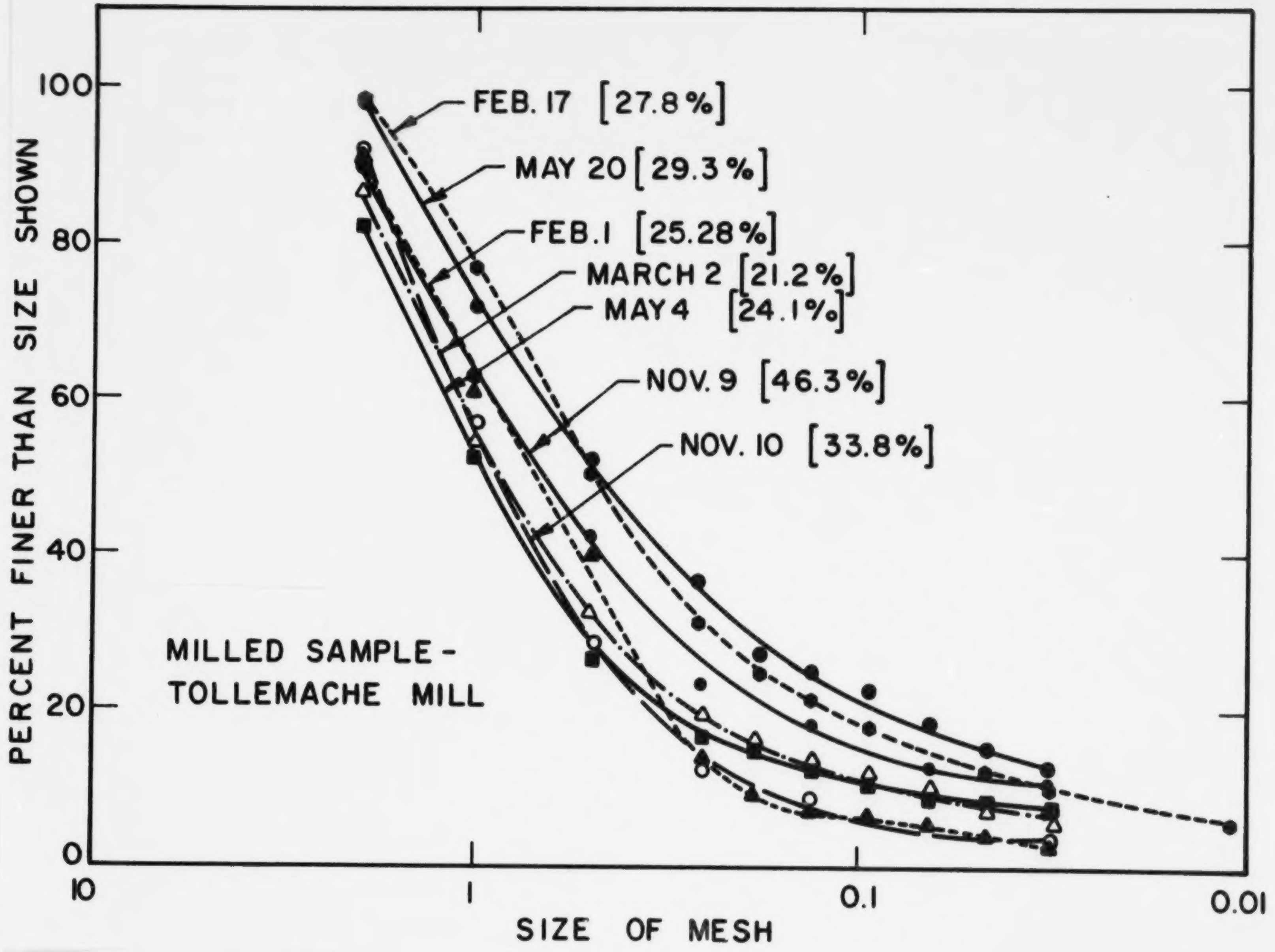


Figure 26. Particle Size Distribution of Various Refuse Samples Taken From Tollemache Mill

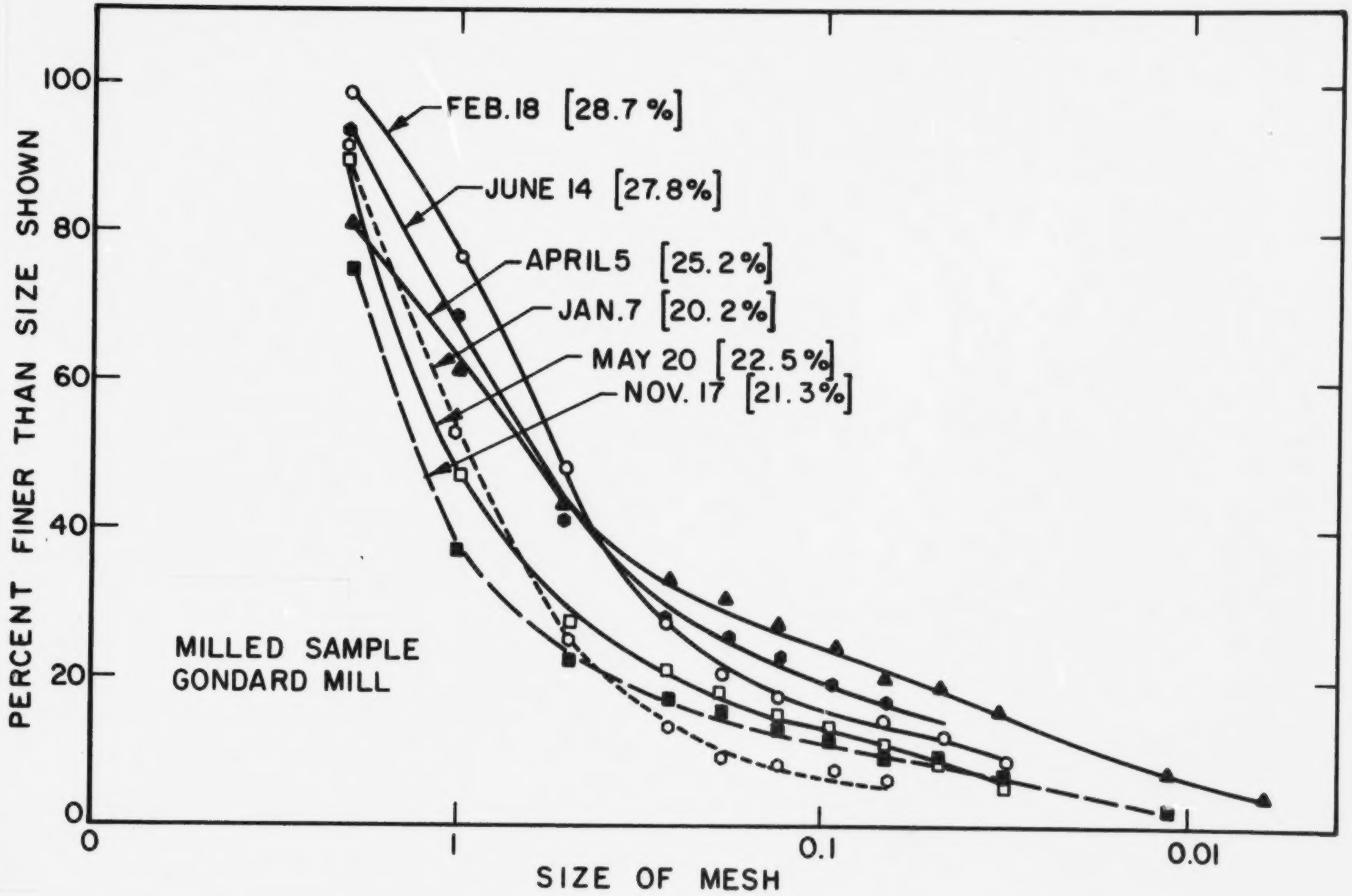


Figure 27. Particle Size Distirbutions of Various Refuse Samples Taken From Gondard Mill

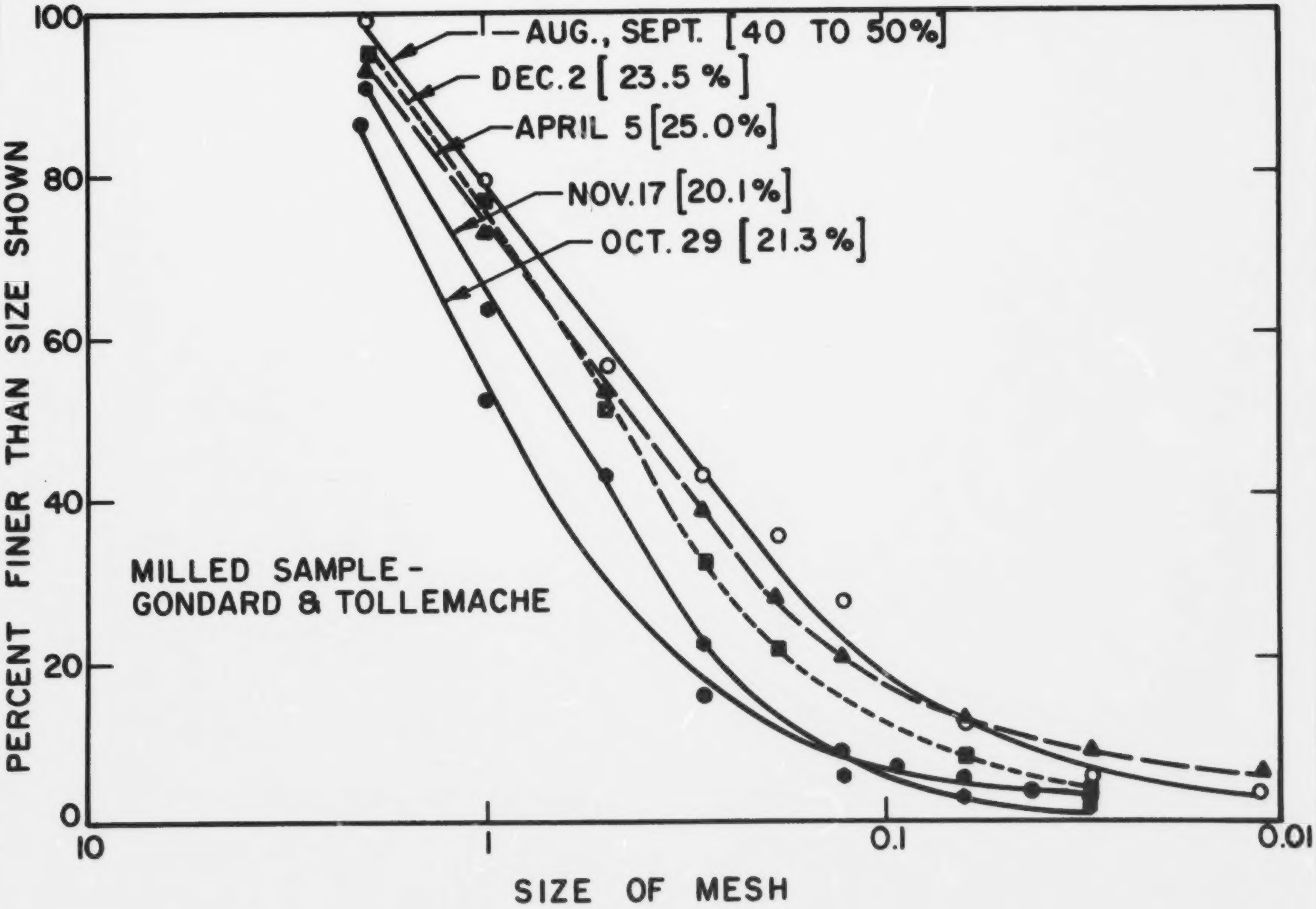


Figure 28. Particle Size Distribution of Various Refuse Samples Taken From Both Gondard and Tollemache Mills

Moisture Content:

The percent moisture contents during the period of study were plotted against time to get a general idea of the seasonal moisture content variation. The results are shown in Figure 29.

The moisture content of milled refuse was found to be fairly constant during the period from October to April. There was a gradual increase in moisture content from 25 percent to 47 percent for the period from May to August. This increase may be due to the heavy precipitation during the summer months and to the change in composition which occurs in the summer, with increased amounts of wet yard wastes, etc.

However, a statistical analysis showed that the moisture content variation alone cannot explain the particle size variation observed throughout the year.

DENSITY

INTRODUCTION:

A practical consideration in milling and compacting refuse for landfill is achieving maximum reduction in volume (i.e., higher densities), consistent with reasonable costs, to assure maximum utilization of disposal space and minimum subsequent settling. Also, it is more economical to transport high density material than low density material to certain limits.

It is important to know whether there is a significant difference in density between milled and unprocessed refuse, and whether large compaction equipment producing considerable vibrations would produce the same or high densities as achieved by milling. For these reasons, tests comparing the densities of milled and unprocessed refuse were conducted under a variety of experimental conditions.

Finally, there is a dearth of information on the effect of refuse bridging in an enclosed space on the resulting refuse density. To study the effect of bridging on density, compressibility tests on milled and unprocessed refuse with and without a container were also performed.

The factors affecting the density of refuse are presented below.

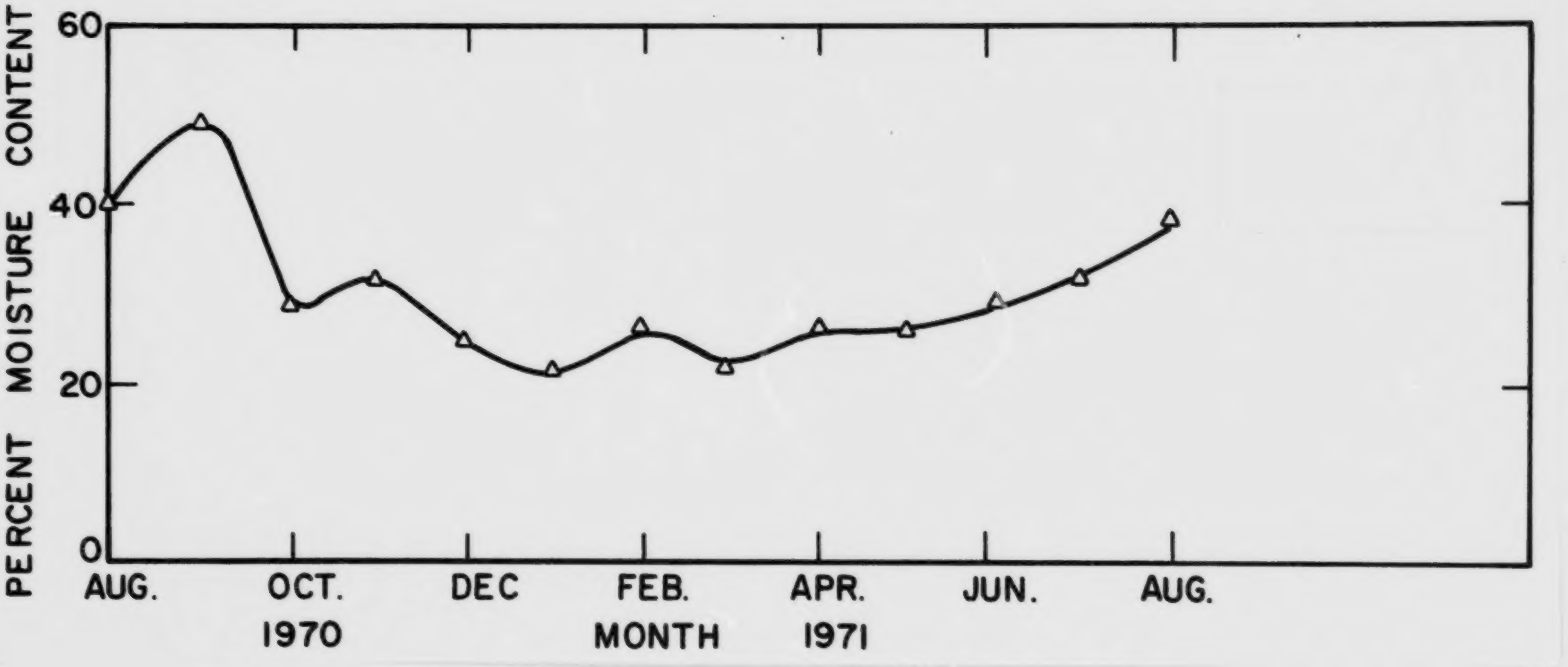


Figure 29. Refuse Moisture Contents Measured Over a One-Year Period

1. The composition of the refuse is important. Depending on the percentage of light and heavy materials, the overall density of a refuse sample will vary considerably.

2. High moisture content of refuse certainly influences the density, not only directly by increasing the weight because of the added weight of the water, but also indirectly by improving the compactability of the refuse.

3. The type of machine used for compacting refuse in a landfill affects the degree of compaction obtained. Several compactors are on the market, but steel-wheeled types appear to give highest densities.

4. Particle size is another factor that must be considered. Refuse broken into pieces normally requires less volume than unaltered refuse and will attain higher densities upon compaction.

5. In addition to the above factors, the number of machine passes, lift height, and spreading thickness will also affect the density.

EXPERIMENTAL PROCEDURE:

Equipment:

A box 23-1/4 x 23-1/4 in. x 35-1/2 in. high was made out of 3/4-in. thick plywood and used as the container for the compression tests (Figure 30). The four sides of the container were fixed together with four 2 x 2 x 1/8-in. thick aluminum angles, and screws were placed at the corners. The bottom plate was fixed using wooden pieces along the sides as shown in the figure. Stick cement was used to fill all the corner openings to prevent leakage of leachate. Care was taken to brace the container properly to make it strong enough to withstand high pressures.

To transfer the applied pressure and the vibrations to the refuse surface an iron plate 22 x 22 in. x 1/2 in. thick was prepared as shown in Figure 31 . A threaded hole 1/2 in. in diameter was drilled to attach the threaded rod from the electromagnetic vibrator. Three pieces of pipe about 5 in. long and 3 in. in diameter were welded on the plate at the proper inclinations to introduce the blunted rod from the air hammer. To measure the amount of vibration transferred from the vibrator to the plate, a channel section 3 in. wide

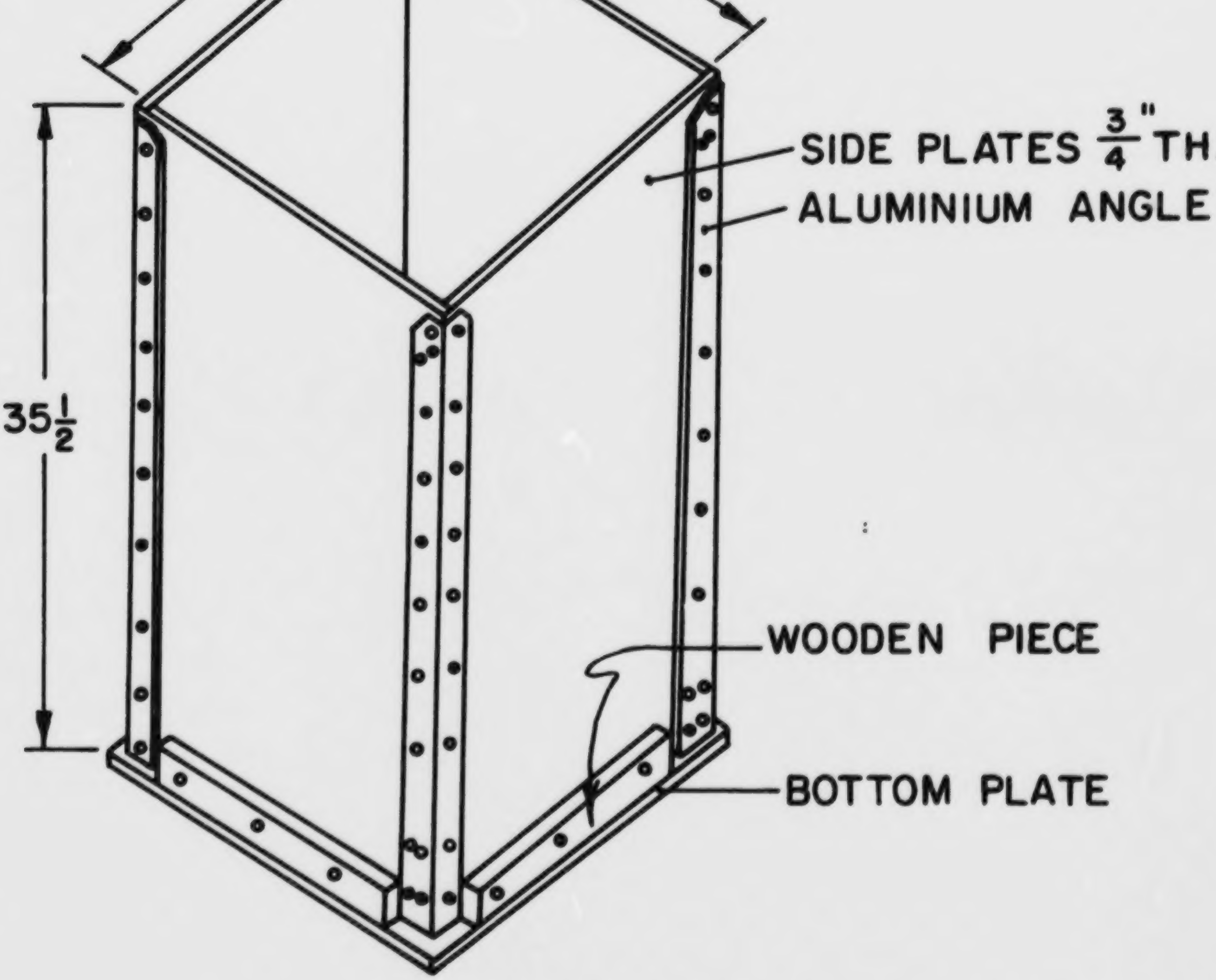
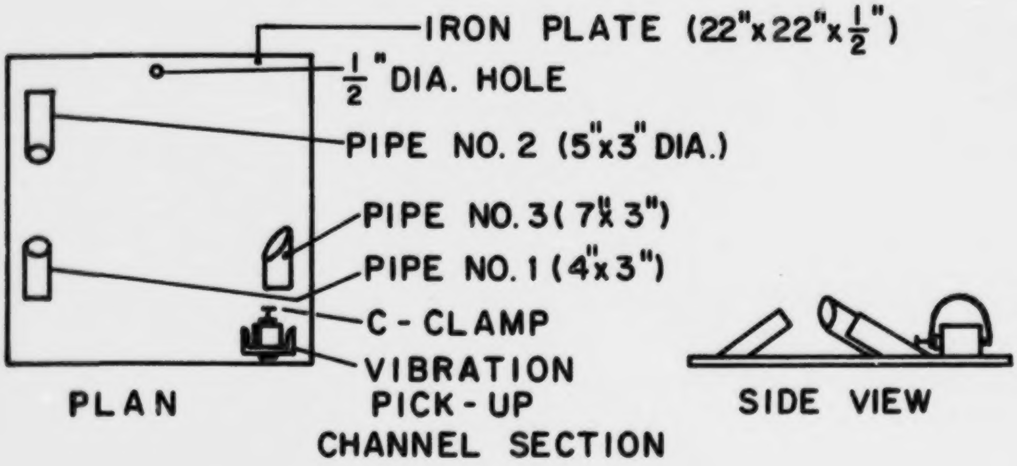

23 1/4
23 1/4
35 1/2
SIDE PLATES 3/4" TH.
ALUMINIUM ANGLE
WOODEN PIECE
BOTTOM PLATE

Figure 30. Container Used for Compression Tests


IRON PLATE (22"x22"x$\frac{1}{2}$")
$\frac{1}{2}$" DIA. HOLE
PIPE NO. 2 (5"x3" DIA.)
PIPE NO. 3 (7"x 3")
PIPE NO. 1 (4"x 3")
C - CLAMP
VIBRATION PICK - UP
CHANNEL SECTION
PLAN
SIDE VIEW

IRON PLATE

Figure 31. Iron Plate Used for Compression Tests

and 4 in. long was welded near one of the corners of the plate. The vibration pick-up was fixed to the channel with a 'C' clamp.

A small box 14 x 14 x 28 in. was made to transfer the applied pressure from the press to the iron plate and thereby to the refuse. The press shaft was larger than the cross-sectional dimensions of the container; thus it was necessary to use the box in between the shaft and the iron plate. The box was made strong enough to withstand heavy loadings, using 2 x 4 in. wooden pieces on the top and bottom, and 2 x 2 in. pieces at each corner and for the bracings as shown in Figure 32. Plywood planks were nailed to all sides.

This entire assembly was placed in a 30-ft. tall compression machine, able to apply loads up to 1,000,000 lbs., which is located in the engineering mechanics laboratories of the University of Wisconsin-Madison (Figure 33). The compression shaft of the machine could be operated either by mechanical screws or by a hydraulic mechanism. A compression cell indicates the exact amount of load applied. Figure 34 is a schematic of the unit.

In order to simulate compaction in a landfill, it was necessary to transfer vibrations to the refuse under compression. This could be accomplished either by vibrating the iron plate or by vibrating the container itself. Since the pressure to be applied was very high (maximum about 120 psi) it was decided to attempt to vibrate the iron plate instead of the complete box.

Of the possible mechanisms for producing vibrations, two were actually used.

A trial test was carried out using a 50-lb.-force electromagnetic vibrator. It was observed that the vibrations transferred to the plate were not as strong as those found on the landfill, so subsequent tests were performed using a stronger vibrating machine. Attempts were made to use a hydraulic hammer for this purpose, but it soon became apparent that the unit was not providing sufficient power. The only alternative was to use an air hammer, even though such a unit is fairly difficult to control and is noisy.

A vibration meter, type 1553A, manufactured by the General Radio Company, was used for measuring the vibrations. A pick-up with one end attached to the meter and the other attached to the vibrating object transfers the signal to the meter for measurement of the amplitude, acceleration, velocity, and jerk of vibrations.

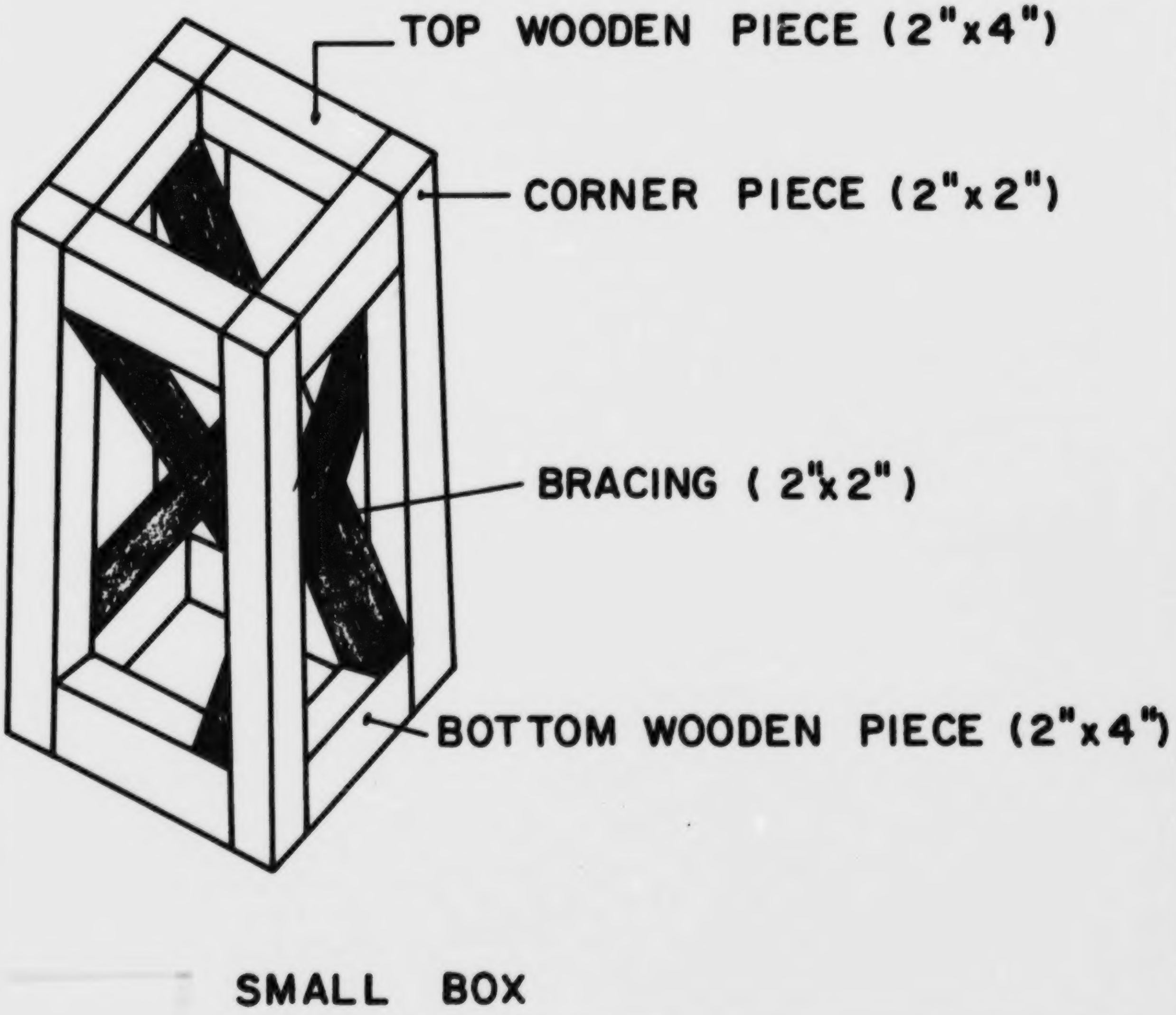

TOP WOODEN PIECE (2"x4")
CORNER PIECE (2"x2")
BRACING (2"x2")
BOTTOM WOODEN PIECE (2"x4")
SMALL BOX

Figure 32. Small Box Used In Compression Tests

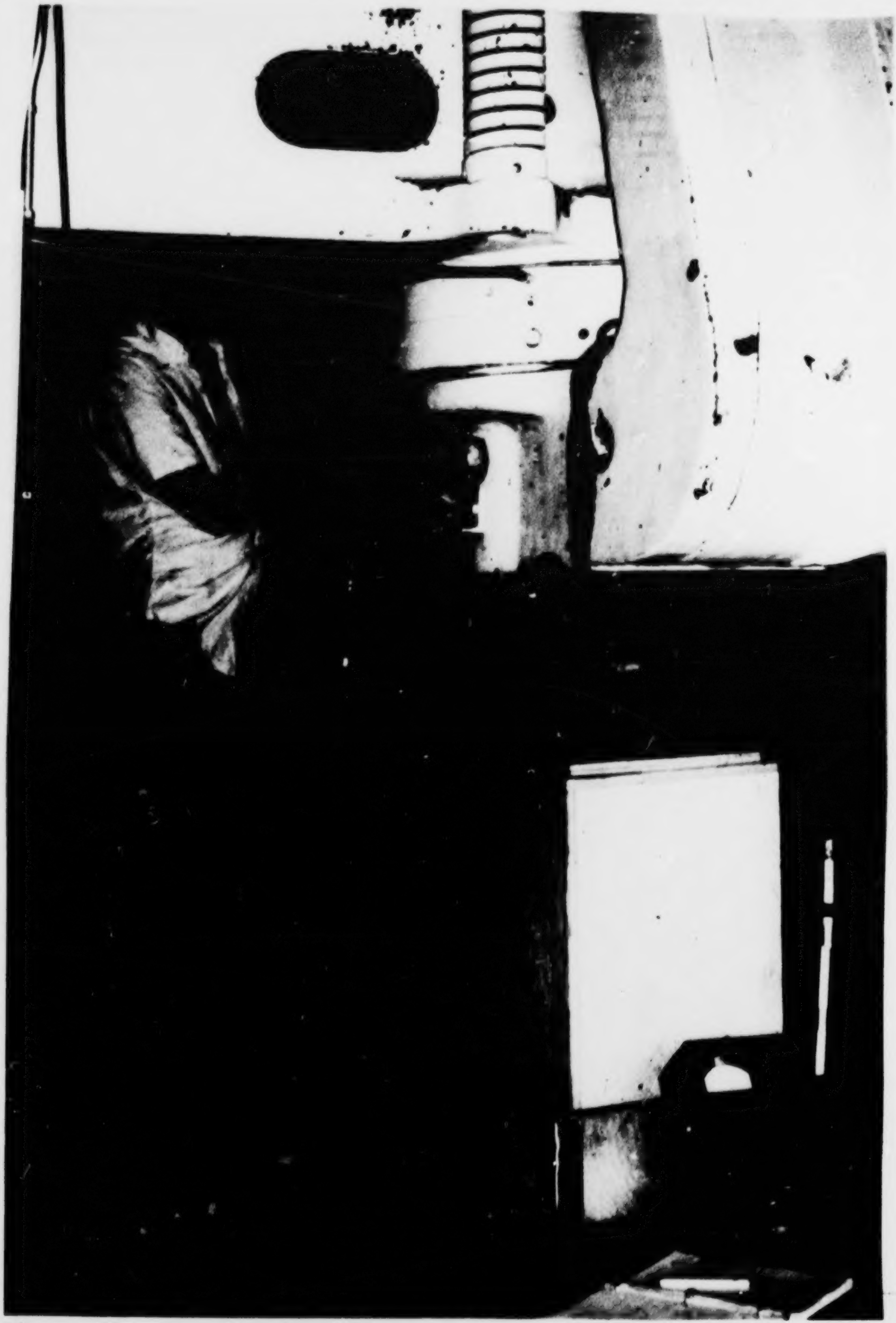


Figure 33. Compression Machine With Air Hammer in Place, Used to Compact Milled and Unprocessed Waste During Laboratory Investigations

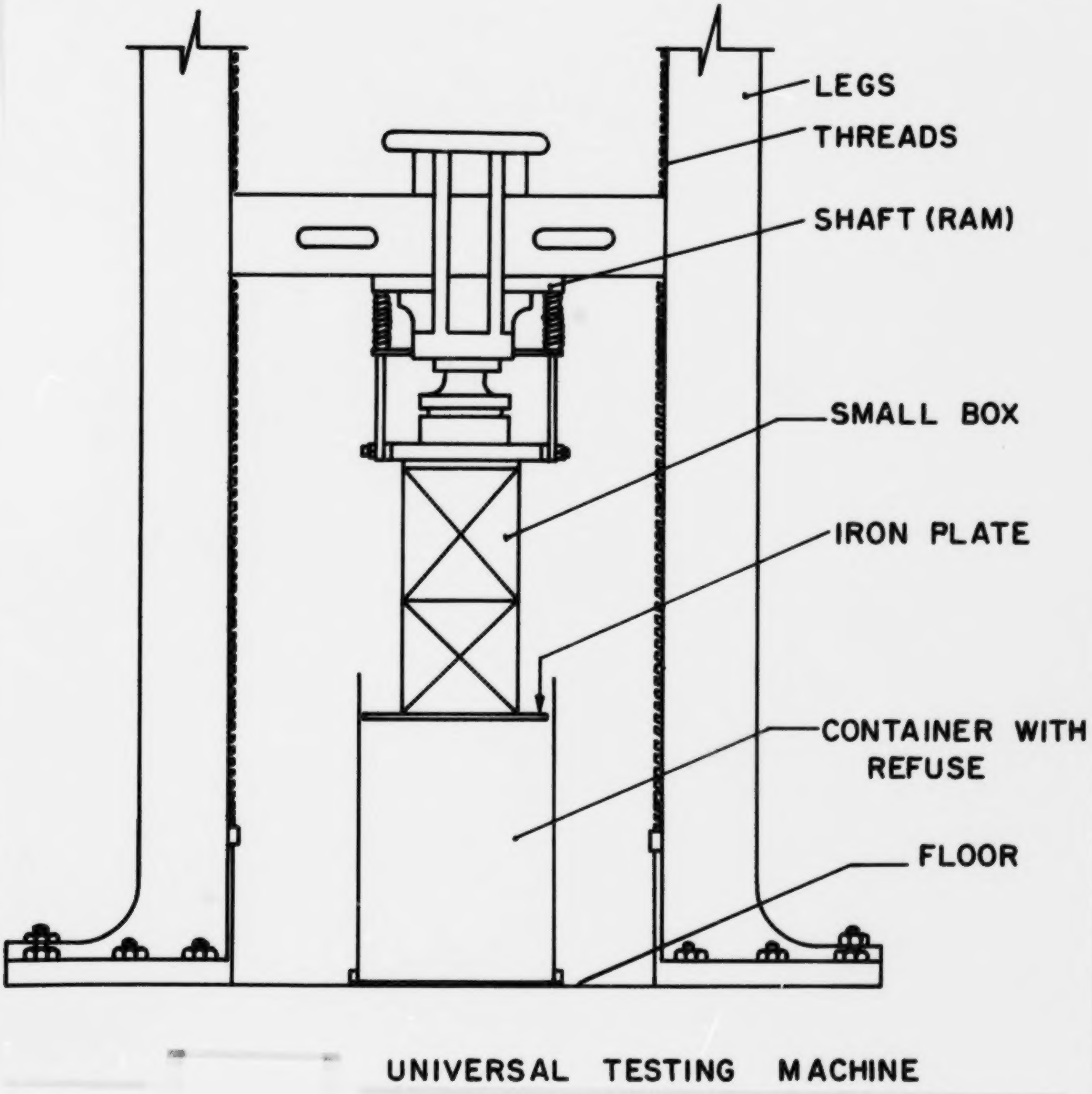

LEGS
THREADS
SHAFT (RAM)
SMALL BOX
IRON PLATE
CONTAINER WITH REFUSE
FLOOR
UNIVERSAL TESTING MACHINE

Figure 34. Universal Testing Machine Used for Compression Tests

Field Study:

A tractor moving across a landfill to spread and compact refuse provides compaction by its absolute weight and also, it is thought, by vibrations it transmits to the refuse. The relative importance of vibration in determining refuse density is not known and is one of the factors considered in this study. In order to make meaningful laboratory experiments possible, the vibrations actually provided in a landfill had to be measured in some fashion.

A vibration meter, as described previously, and a metal plate 4 x 3 in. x 1/16 in. thick were brought to the landfill site. The meter was set on milled refuse approximately 8 ft. deep, and 7 ft. away from the path a D-7 Caterpillar tractor was working. The pick-up itself was placed on the metal plate which was then placed on the refuse surface about 4 ft. away from the wheels of the tractor. Measurements were taken when the tractor was moving both in the forward and reverse directions, and are shown in Table 27.

TABLE 27

Vibration Study on Landfill

	Displacement (mils) Triplicate				Acceleration (in/sec^2) Triplicate			
Direction	1	2	3	Average	1	2	3	Average
Reverse	15	20	15.6	14.02	100	90	79	70.2
Forward	10	-	9.5		30	55	57	

The results in Table 27 indicate that when the tractor moves in reverse it transfers vibrations of greater displacement and acceleration than when it moves forward. The average displacement was found to be 14.02 mils (1 mil = 1/1000 in.), and the frequency crudely measured at approximately 6 cycles/sec.

Laboratory Tests:

Only one day's refuse was used for all the tests indicated in Table 28 to minimize the effects of having large composition changes from test to test. Approximately 1 ton of residential refuse, of apparently uniform composition, collected August 10, 1971, was dumped on a cement slab. About one-half of the refuse was dumped in the feed hopper and milled with the Tollemache mill. The milled refuse was placed in plastic bags which were tied securely. The unprocessed refuse was also placed in plastic bags after discarding a few large items such as cardboard, concrete blocks, and long metallic pieces. These bags were also tied securely to avoid loss of moisture. All the bags with milled and unprocessed refuse were brought to the laboratory the next morning.

Samples of about 200 gms. each were taken from three randomly selected bags of milled refuse, and analyzed for moisture content. The moisture was found to range between 43.9 and 45.5 percent on a dry weight basis.

The ten tests indicated in Table 28 were carried out on both milled and unprocessed refuse. The vibrations were classified arbitrarily as light, medium, or heavy for the purpose of this experiment. The displacement measured in the field study is approximately the same as the medium classification used in the laboratory.

TABLE 28

Compression Tests

Test No.	Refuse Sample	Test
1	Milled	No vibrations, with container
2	Milled	Light vibrations, with container
3	Milled	Medium vibrations, with container
4	Milled	Heavy vibrations, with container
5	Milled	No vibrations, without container
6	Unprocessed	No vibrations, with container
7	Unprocessed	Light vibrations, with container
8	Unprocessed	Medium vibrations, with container
9	Unprocessed	Heavy vibrations, with container
10	Unprocessed	No vibrations, without container

Test Without Vibrations

The large container was placed so that its center coincided with the center of the ram of the press. Each bag of refuse used was then weighed accurately to 0.1 lb. and emptied into the container. Refuse was spread with a long wooden board to make the surface somewhat even. When the container was filled completely with a known weight of refuse, the iron plate shown in Figure 31 was placed on the refuse, followed by the small box shown in Figure 32. The initial density was computed at this time by measuring the volume occupied by the refuse within the container and compressed slightly by the iron plate and the small box. Next the compression shaft was lowered until it just touched the top of the small box. The container, iron plate, small box, and the position of the shaft were given a final check at this point to make sure that everything was in line.

Gradually the load was increased by 500-lb. increments until 2,000 lbs. was reached and then by 1,000- to 2,000-lb. increments until the end of the test. Measurement of the empty space at the top of the container was taken for each corresponding load to calculate the densities at various pressures. When the plate was not absolutely level, a measure of its location was taken on both high and low sides to calculate the average depth. The test was continued until there was little or no movement of the iron plate after an increase in load of about 2,000 lbs. At this point the shaft was raised and the refuse was left in the container under the weight of the iron plate and the small box. One minute was allowed for relaxation of the refuse after which the final measurement of the plate location was taken for calculation of the springback. The test with unprocessed refuse was carried out in similar fashion.

Tests With Vibrations

A similar procedure was used when tests with vibrations were undertaken. The compressor was parked outside the laboratory and the medium size air hammer of 60-lb. weight was connected to the compressor with a rubber hose. A blunt, hexagonal rod about 30 in. long was attached to the hammer. The other end of the rod was introduced into pipe no. 1, shown in Figure 31, which had been welded securely to the iron plate. The air hammer was held in place by one person.

The vibrator meter pick-up was attached with a 'C' clamp to the channel section provided on the iron plate. Everything was checked for safety before the tests were begun. The compressor was started and the vibration meter turned on.

It was decided to vary the amount of vibration by varying the pressure by which the air hammer was forced against the iron plate, and by varying slightly the amount of air delivered to the hammer. The three levels of vibration were characterized as light, medium, and heavy, where the vibration meter served to check on the actual amount of vibration delivered. The average amplitude of vibrations measured in the field study was 14.02 mils. Therefore, the amplitude for light vibration was selected to average around 10 mils, medium vibration around 20 mils, and heavy vibration between 30 and 40 mils. Although the vibration system seemed at first to be rather crude, experience made it possible to achieve and maintain a reasonably uniform vibration level.

Loading was started by lowering the shaft until a momentary high pressure of 200 lbs. was achieved. This was necessary to hold the small box and iron plate securely when vibrating was begun. The vibration was started by allowing the air to pass through the hammer. The amplitude of vibration was adjusted to meet the desired level by adjusting the throttle valve controlling the amount of air allowed to pass to the hammer and by trying to use constant pressure on the hammer. The loadings and measurements of iron plate location were recorded to calculate the density of refuse at the various pressures and amplitudes of vibration. The amplitude of vibration was checked continually during the test and adjusted whenever necessary. The test was terminated after what seemed to be an unsafe situation was attained or after there was little or no change in iron plate location after a 2,000-lb. increase in loading.

Tests Without Container

After the compressibility tests using the container were completed, the tests were milled and unprocessed refuse were carried out without using the container. The plywood piece at the bottom of the container was detached and all the screws from two opposite corners were removed except for six, one each at the top, bottom, and middle, which were loosened but not removed.

The compressibility tests as performed without vibration were carried out in the normal fashion until about 700 lbs. of loading was achieved. At this point the refuse was under sufficient pressure that the remaining six screws could be removed from the container and the sides taken away without loose refuse falling out of the compression zone. The height of the refuse under compression was measured and the corresponding loading was recorded. The compression test was then continued in the normal manner noting the loading and corresponding height of the refuse. When the cross-section of refuse seemed to change, as when some of the components of the refuse were found projecting out, a new cross-sectional area was measured. This was done by holding the corners of a wooden piece tightly against the bulging refuse, and measuring the apparent length and width of the refuse under compression. The test was terminated when little or no compression was attained after 2,000 lbs. of increased loading was applied.

RESULTS AND DISCUSSION

Compressibility Tests With Container:

Figure 35 shows the plots of density in lbs./cu.yd. vs. pressure in lbs./sq.in. for eight compressibility tests using the container. The results are on a wet-weight basis. The following observations can be made from the curves.

All the curves show a rapid increase in density to a value of about 15 psi pressure. After that point, increased pressure results in relatively small density increases. It is also shown that the curves do not diverge or converge as the pressure increases. Therefore, the numerical increase in density by milling is approximately the same at all pressures, but the percent increase decreases as the pressure goes up.

The curves for unprocessed refuse, and especially the one without vibrations, show a fairly wide scatter of points which deviate somewhat from the curves as shown. This scatter may be explained by the breaking or flattening of various components of refuse, such as glass bottles and cans, which resist pressure up to a point before they are suddenly crushed.

During the test on milled refuse with light vibrations, the amplitude of vibrations was below the desired range. This was especially noticeable in the 52- to 98-lb./sq.in. pressure range. Note that the resulting density is found to be lower in this range, but that the density seemed to increase during the test on unprocessed refuse with medium vibrations in the 30- to 70-lb./sq.in. pressure range.

The density of milled refuse was higher than that of unprocessed refuse under all pressures considered. The average initial density as placed in the container was 386 lbs./cu.yd. in the case of milled refuse and 313 lbs./cu.yd. in the case of unprocessed refuse samples under study.

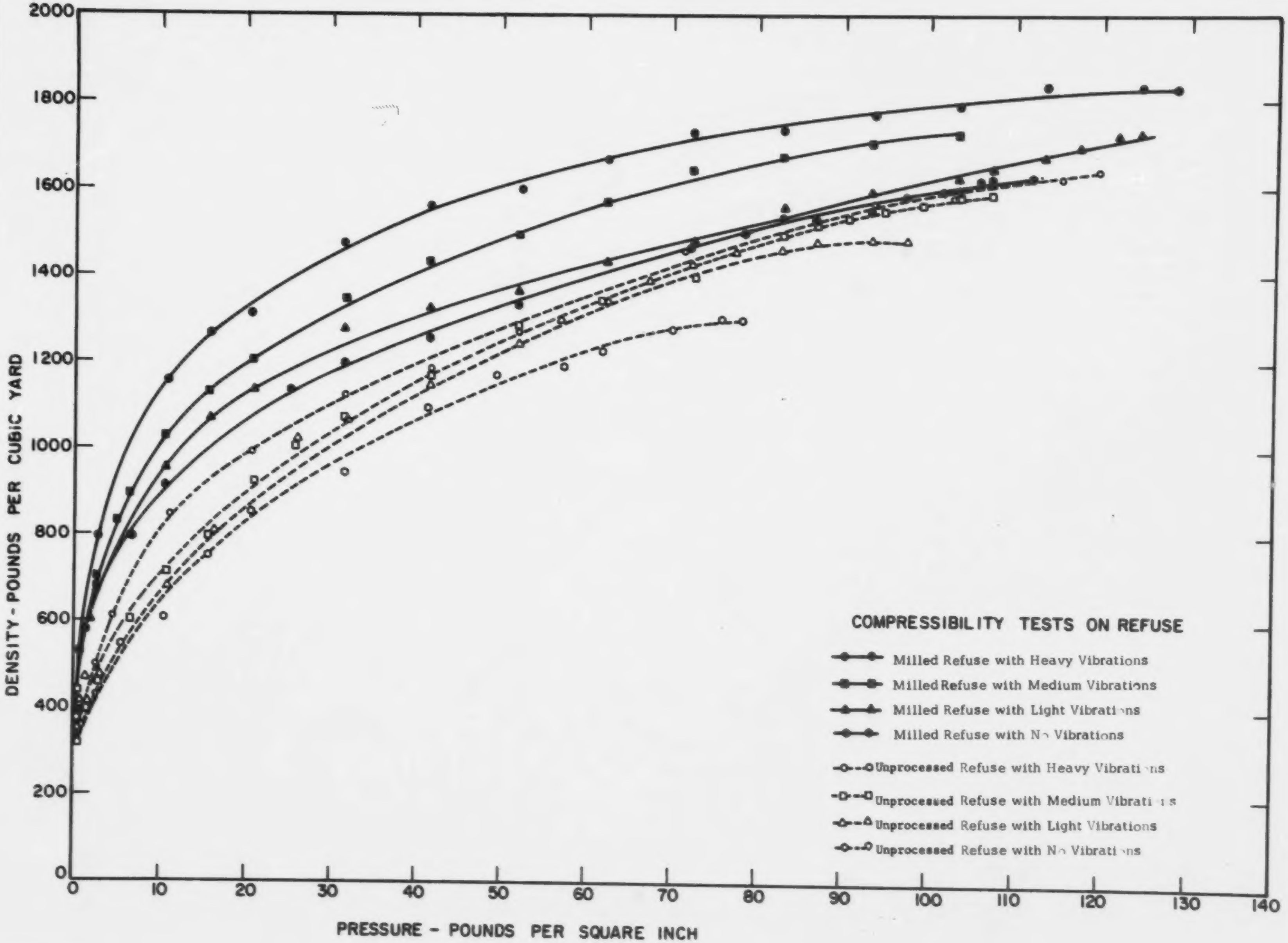


Figure 35. Compressibility Tests on Refuse

It is clear from the plots that the density of both milled and unprocessed refuse was increased with increasing amplitude of vibrations applied during compression. Also the density of milled refuse at all levels of vibrations was found to be higher than the corresponding density of unprocessed refuse. The range of density for milled refuse was 1,515 to 1,750 lbs./cu.yd. going from zero to heavy vibrations while the corresponding densities for the unprocessed refuse were 1,305 to 1,493 lbs./cu.yd., at 80 psi pressure. Table 29 gives the values of densities at 5 and 50 psi pressures, and also gives the increase over unprocessed refuse and the percent increase over no vibrations.

Table 29 shows that the percent increase of density of milled over unprocessed refuse is higher at 5 psi pressure than at 50 psi pressure, the values being about 47 percent and 10 to 25 percent, respectively. The percent increase from vibrations is more important at low pressures than at high pressures in the case of unprocessed refuse, while it is relatively independent of pressure in the case of milled refuse. It is concluded that milling affects the density more at lower ranges of pressure than at higher ranges, and that the percent increase of density obtained by milling refuse is more important than the percent increase in density obtained simply as a result of vibrations.

The springback tests indicated that the reduction in density due to relaxation of the refuse after the external pressure was released was 21.9 percent with milled refuse and 22.1 percent with unprocessed refuse. This difference is insignificant. Table 30 indicates the maximum density attained after compression and the reduction in density due to springback.

The Caterpillar tractor used at Madison's Refuse Reduction Plant is a D-7 1960 model, weighing approximately 35,000 pounds. The overall size of the tractor is 18 ft. x 7-1/2 ft. x 10 ft. in height with two tracks which are 14 ft. x 14 in. each. The average pressure exerted by the tracks on the landfill would be approximately 7.5 lbs./sq.in. From the plots at this pressure, the expected density in the landfill using the medium vibration case which comes closest to the vibrations measured in the field study, would be approximately 960 lbs./cu.yd. with milled refuse, while the density of unprocessed refuse would be approximately 660 lbs./cu.yd. under the same conditions. These figures correspond well with the values established by field density measurements at Madison and other test sites. Values cited range from appoximately 900 to 1,000 lbs./cu.yd. in the case of milled refuse and 600 to 700 lbs./cu.yd. in the case of unprocessed refuse. Note that moisture content variations will have a significant effect on these values and that they are strictly

TABLE 29

Laboratory Density Test Summary*

Refuse	Vibrations	Pressure of 5 Psi Density	Pressure of 5 Psi % Increase over Unprocessed	Pressure of 5 Psi % Increase over no Vibration	Pressure of 50 Psi Density	Pressure of 50 Psi % Increase over Unprocessed	Pressure of 50 Psi % Increase over no Vibration
Unprocessed	None	500	-	-	1150	-	
	Light	538	-	7.6	1250	-	8.7
	Medium	560	-	12.0	1258	-	9.4
	Heavy	640	-	28.0	1290	-	12.2
Milled	None	755	51.0	-	1330	15.6	-
	Light	790	46.8	4.6	1380	10.4	3.8
	Medium	828	47.8	9.7	1490	18.9	12.0
	Heavy	940	47.0	24.5	1614	25.1	21.4

* Moisture content of refuse ranged from 43.9 to 45.5 percent on a dry-weight basis.

TABLE 30

Summary of Springback Results

Refuse	Vibrations	Maximum Density lbs/yd^3	Maximum Pressure psi	Density after Springback lbs/yd^3	Reduction in Density lbs/yd^3	% Reduction	Average % Reduction
Milled	None	1630	112	1250	395	24.3	21.95
	Light	1712	124.5	1310	402	23.6	
	Medium	1722	104	1245	477	27.6	
	Heavy	1830	128	1605	225	12.3	
Unprocessed	None	1305	78	-	-	Practical difficulty	22.07
	Light	1487	98	1260	227	15.3	
	Medium	1595	100	1255	340	21.3	
	Heavy	1640	120	1154	486	29.6	

valid only for the refuse used for these studies. It is felt, however, that the relative increase in density obtained with milled refuse in these tests will also be found under most field conditions.

Based on the above figures it can be concluded that there is a definite increase in density with milled refuse in a landfill when compared to landfills with unprocessed refuse. A further increase in density can be achieved with either milled or unprocessed refuse by vibrations applied during compaction of the refuse by heavy compacting equipment.

Bridging Effect:

Figure 36 shows the results of four special bridging effect tests which were carried out on a sample of refuse collected April 20, 1972. The composition of this refuse was different from the samples used for the previous density tests. The average moisture content of this sample was 36.5 percent on a dry weight basis.

The plot shows again that the density of milled refuse was consistently higher than the density of unprocessed refuse. This was true whether or not a container was used, and at all pressures applied. The density of milled refuse in the container was 1,545 lbs./cu.yd. at 105 psi pressure while with unprocessed refuse the corresponding density was 1,285 lbs./cu.yd.

The other two curves represent the results of tests run without a container, in an attempt to eliminate possible bridging of refuse due to the effect of the container walls. If the bridging effect was large, compressibility tests like those used in this study would not give results valid for actual landfill situations. Again, higher densities were obtained at all pressures with milled refuse. Note that a bridging effect was present with both milled and unprocessed refuse, where an increased density was attained at all pressures when a container was not used. The reduction in density from use of a container was calculated by averaging the density values from the curves at 30, 60, and 90 psi pressures. It was found to be 4.3 percent and 9.1 percent in the cases of milled and unprocessed refuse samples respectively. These figures give an indication of the error introduced by at least this one effect in applying the results of this study to field conditions.

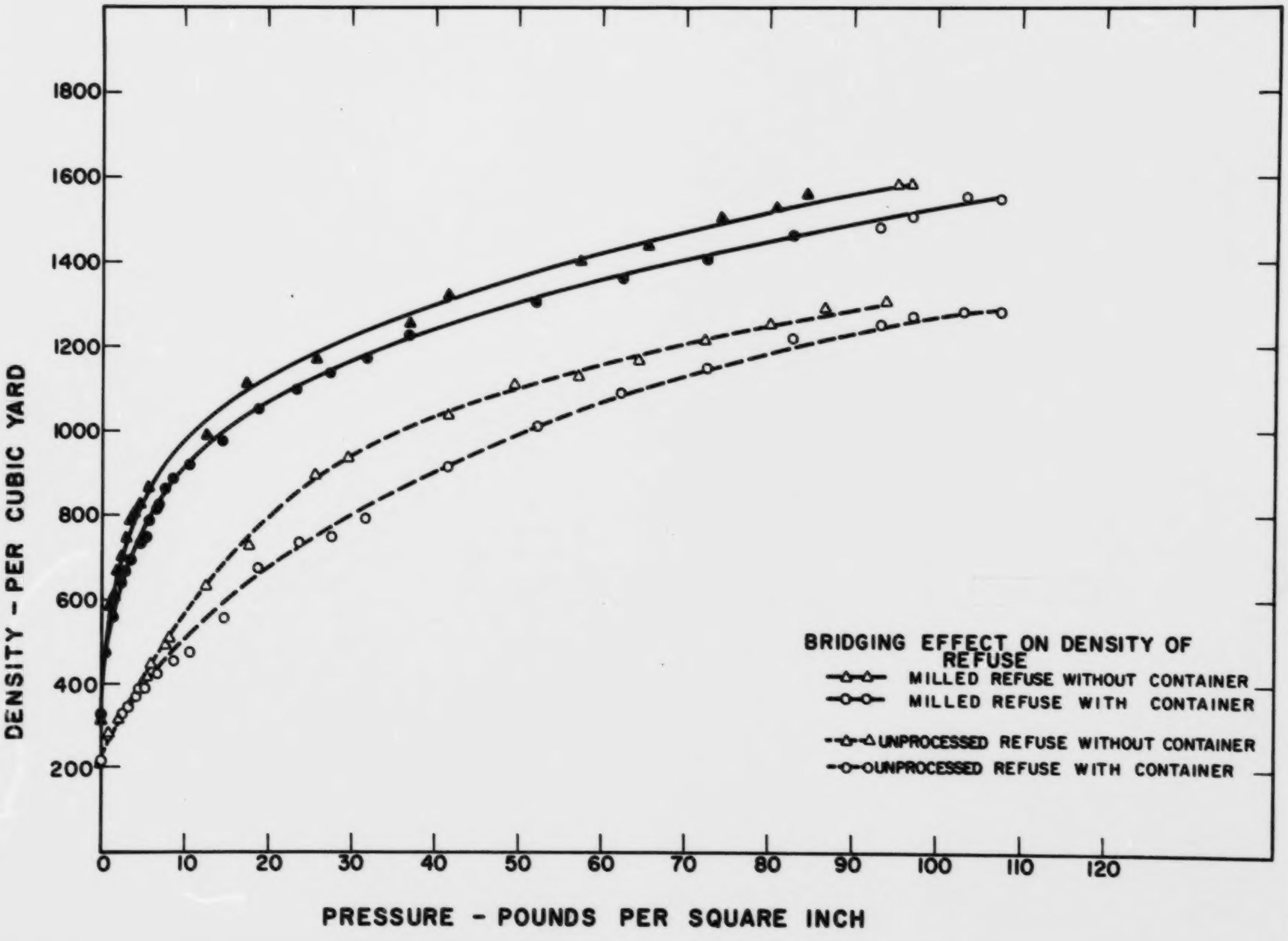


Figure 36. Effect of Bridging on Density of Refuse

IV-B - Field Density Tests

Field density tests comparing milled and unprocessed refuse were first completed in 1967 and 1968 at the Olin Avenue site. All cells, both milled and unprocessed, were compacted to a 6-ft. depth by a D-7 Caterpillar tractor. Results of these tests indicated that milled refuse in a landfill situation has an average actual density of 930 lbs./cu.yd., while unprocessed refuse has an average actual and effective density of 810 lbs./cu.yd. and an average effective density of 570 lbs./cu.yd., all figures on a wet-weight basis. For the purpose of comparing landfill space savings, the effective refuse density figures are more meaningful because they include the volume of cover dirt used (Table 31). Results of the Olin Avenue field density tests were in question, however, because of the lack of control over such aspects as compaction time, cover dirt usage, moisture content of the refuse, and size of the cells used for comparison. Thus, more in-depth tests were deemed necessary.

The new density tests were designed to compare in-place density of milled and unprocessed refuse placed with equal compactive effort and to compare in-place densities of milled and unprocessed refuse placed under normal sanitary landfill construction. Cell I was to be filled with unprocessed refuse. Cell II was to be filled with milled refuse; compaction time was to equal that used on Cell I. Cell III was to be filled with milled refuse using only the compactive effort necessary to achieve a good sanitary landfill. Cover dirt was to be placed only on the top of each cell. Further description and the results of the tests are presented below.

EXPERIMENTAL PROCEDURE

Three cells with 2:1 side slopes were excavated adjacent to the city-owned Truax landfill in 1972. Cell I was constructed with a ramp to allow city packer trucks access to the fill working face, thus minimizing blowing paper problems. Ramps were not needed on Cells II and III since blowing problems are almost nonexistent with milled refuse. The 8-ft.-deep cells were designed to provide a volume of over 2,000 cu. yd. and to be able to hold approximately 1,000 tons of refuse each (Figure 37).

TABLE 31

Olin Avenue Field Density Tests (1967-68)

Cell No.	Refuse Volume (cu. yd.)	Cover Volume (cu. yd.)	Refuse Weight (wet-tons)	Actual Refuse Density (lb./cu. yd.)	Effective Refuse Density (lb./cu. yd.)
Milled Cells					
1	1,120	-	534	950	950
3	1,500	-	703	940	940
9	1,090	-	474	870	870
10	1,820	-	689	760	760
11	2,090	-	844	810	810
15	1,370	-	617	900	900
17	1,340	-	733	1,090	1,090
21	1,250	-	709	1,130	1,130
			AVE.	930	930
Unprocessed Cells					
4A	3,010	670	1,045	700	570
4B	1,440	550	683	950	690
12	4,390	2,190	1,456	660	440
18	2,865	1,455	1,268	880	590
22	1,245	635	548	880	580
			AVE.	810	570

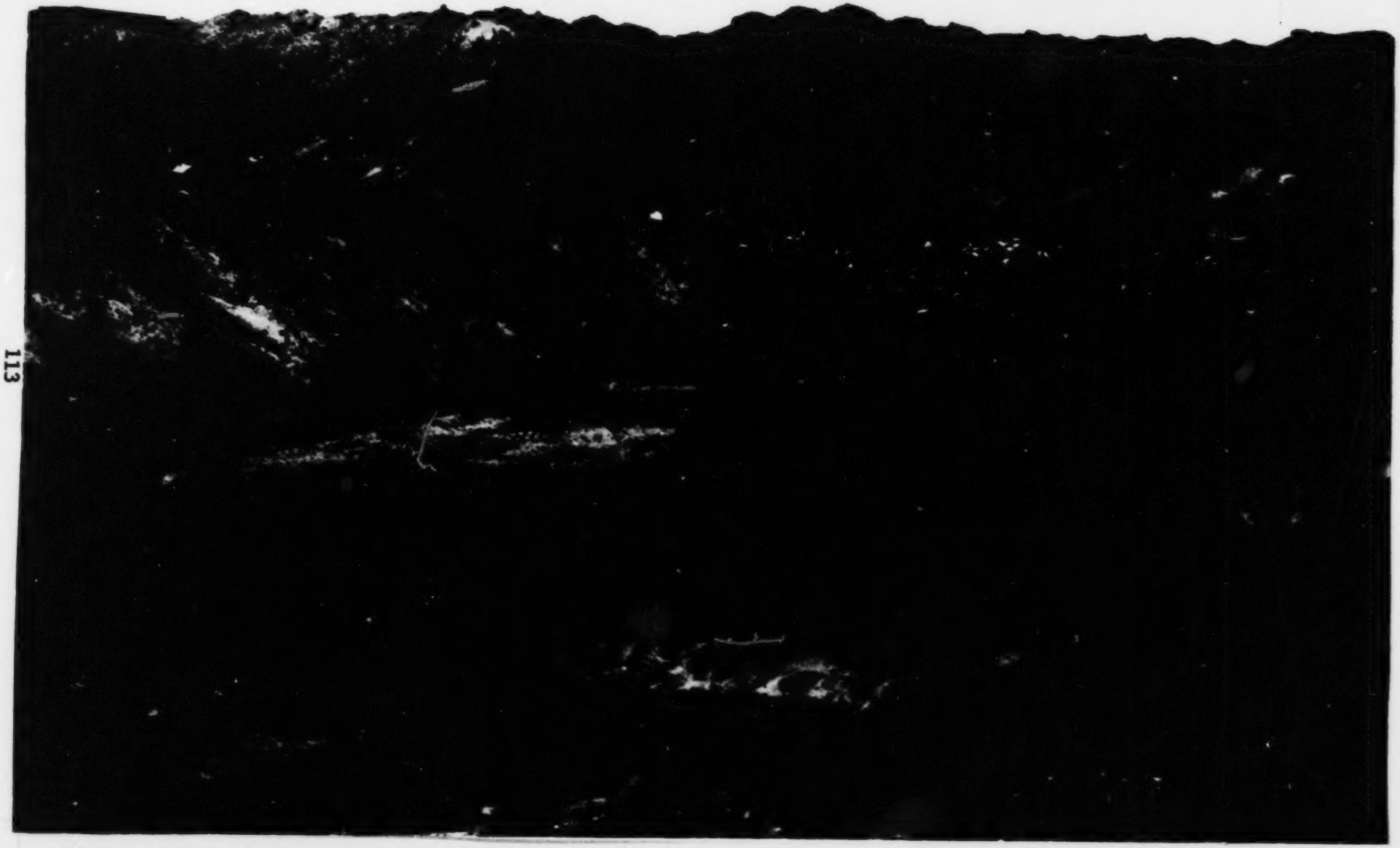


Figure 37. One of Three 2,000 Cu. Yd. Cells Constructed at Truax Landfill to Conduct Field Density Tests for Milled and Unprocessed Wastes

A detailed grid system was constructed over each unfilled cell. Initial cross sections were taken using common surveying techniques at designated points on the grid system. These points were established as references and used in all further surveys. The cells were surveyed following completion of the filling process and also after placement of cover dirt. Surface borings were also taken to determine cover dirt depths. All data were then plotted and volumes determined by planimeter.

The composition of refuse used in this test is typical of Madison's refuse as determined by numerous separation studies. Results of these studies are given in Appendix N. Refuse used in filling the cells was that regularly collected by city packer crews on normal working runs covering the entire city. No bulky items such as white goods or furniture were collected in the loads. The cells were filled in July and August (Figure 38).

Moisture content for the two milled cells was determined by taking six 1-lb. samples of milled refuse as delivered to the site throughout each day. The samples were dried at 75° C. to a constant weight. Moisture content was calculated on a dry-weight basis (DWB).

For consistency, it was felt that moisture content of the unprocessed refuse should also be determined after milling. Thus throughout the daily filling operation of Cell I, 200- to 300-lb. samples of unprocessed refuse were taken from the cell and stored in a city packer truck. The truck and its load were then taken to the refuse reduction plant where the unprocessed refuse sample was milled. Six 1-lb. samples were then collected and moisture content was determined as described above.

A final cover of dirt was placed on the cells once each cell had been filled and surveying had been completed. The operator, who is experienced in working on sanitary landfills, was instructed to place only as much dirt on each completed cell as would be used under ordinary sanitary landfill conditions.

Cover dirt volumes were measured in the borrow pit and in place by survey cross sections. Cover dirt weights, moisture content, and in-place densities were also used to determine volumes. Moisture content of the cover dirt was determined by oven drying a 1,300-gm. sample to a constant weight at 75° C. Four dirt samples were taken each day that cover was applied.

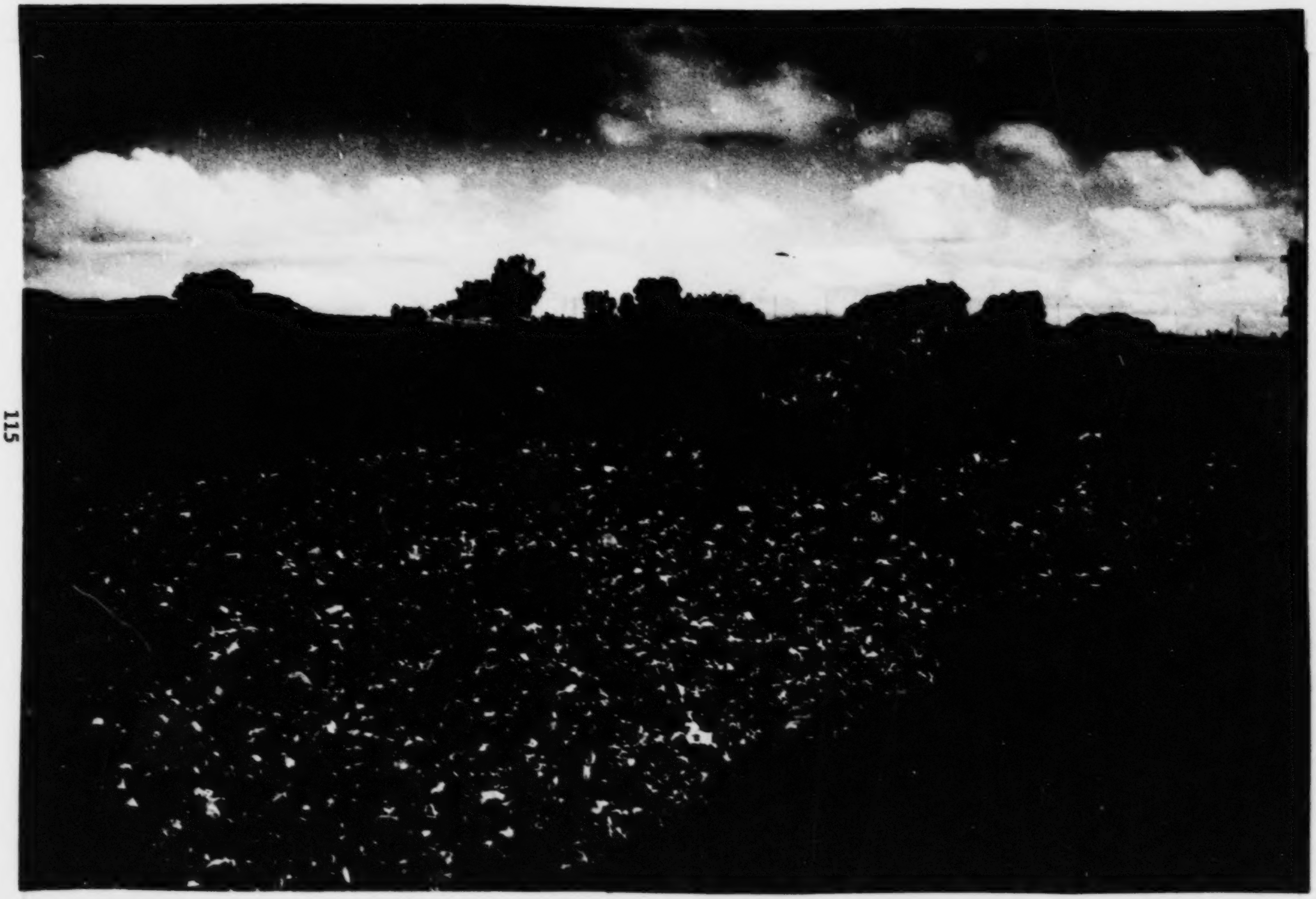


Figure 38. Pit Partially Filled With Milled Refuse During Density Tests

A Caterpillar 950B steel-wheeled compactor was used to spread and compact the refuse (Figure 39). Great effort was taken to accurately record compaction time used on each cell. The test plan called for equal compactive effort to be expended on Cell I, unprocessed refuse, and Cell II, milled refuse; Cell I was to be filled under normal sanitary landfill conditions. Cell III, milled refuse, was to be filled using a minimum of compactive effort. The compaction time used during the addition of cover to each cell was also recorded.

The test began with placement of unprocessed refuse in Cell I on July 17, 1972. As stated, the cell was equipped with a ramp to allow city packer trucks to deposit their loads as near the fill face as possible. The cell was filled under normal sanitary landfill conditions, except that cover dirt was applied only on top of the cell, and not to the working face, at the end of each day. The inclined-face method of compaction was used.

Packer trucks were carefully weighed at city scales, and care was taken not to allow a truck to deposit its load unless its weight had been recorded. Cover dirt was only applied to the top of the cell, thus maximizing the cell volume in relation to refuse placed. Polyethylene sheeting was used to cover the exposed portions of the cell at the end of each day's operation. Detailed data were kept on compaction time, moisture content, and cover dirt use, as previously explained.

Following completion of Cell I on July 25, 1972, filling of Cell II with milled refuse was started. All procedures that applied in filling Cell I were used with Cell II. Careful controls were initiated to guarantee that the same amount of compaction time was applied to Cell II as to I. Approximately the same wet weights were placed in both cells. The cell was completed on August 2, 1972.

Cell III was filled with milled refuse between August 2 and 11, 1972. Approximately 9 percent more refuse was placed in this cell than in the previous two. The only difference between construction of this cell and the previous two was that the landfill operator was instructed to use the least compaction time necessary to afford a good landfill operation.

Figure 39. Pushing Milled Refuse With a Steel-Wheeled Compactor

RESULTS

Compaction:

As mentioned above, nearly equal weights of unprocessed and milled refuse were placed in each cell. Table 32 contains all pertinent data in respect to weight, both wet and dry, final volumes of the in-place refuse prior to cover dirt addition, and compaction time used to place the refuse.

TABLE 32

Wet and Dry Weights and Total Volume of In-Place Refuse vs. Compaction Time

	Weight (Tons)		% Moisture	Volume	Compaction	
	Wet	Dry	(DWB)	Cu. Yd.	Hrs.	Min./Dry-ton
Cell I*	1114	806	37.5	1992	21.96	1.6
Cell II**	1139	745	51.7	1598	21.96	1.8
Cell III**	1236	779	58.7	1938	12.33	0.9

* Unprocessed refuse
** Milled refuse

Two important facts may be observed from this data:

1) On a dry-ton basis, 8.2 percent more refuse was placed in Cell I than Cell II; but the volume of in-place refuse in Cell I was 24.6 percent greater than Cell II, compaction time being equal.

2) Again on a dry-ton basis, approximately 3.5 percent more refuse was placed in Cell I than in Cell III; at the same time the volume of Cell I is approximately 3 percent greater than Cell III. But to achieve these nearly equal figures required a 78 percent increase in compaction time on Cell I as compared to Cell III.

Cover Material Requirements:

Dirt in this test was to be placed as an intermediate cover; that is, enough dirt was to be used to completely cover the material in a manner similar to the application of intermediate cover in sanitary landfill operations. Table 33 contains a comparison of the cover dirt applied to each cell and a comparison of the methods used to determine the amount of dirt used. Also included is a comparison of machine time needed to spread and compact the dirt.

TABLE 33

Cover Material Volume and Machine Time Used In Its Application

	Borrow Pit-Cu.Yd.	In-Place--Cu.Yd. Cross Section Method	In-Place--Cu.Yd. Field Density Method	Average Volume-Cu.Yd.	Compaction Time--Hrs.
Cell No. 1*	292	286	281	286	2.58
Cell No. 2**	124	128	137	130	1.75
Cell No. 3**	150	151	160	154	1.80

* Unprocessed refuse
** Milled refuse

Data in Table 33 indicate that the average cover dirt requirement for the milled refuse cells was approximately 50 percent of that required on the unprocessed cell.

Densities of Milled and Unprocessed Refuse Cells:

Table 34 contains all pertinent data for density computations. Table 35 shows the percentage increase or decrease of the densities calculated in Table 34 using Cell I as a base.

TABLE 34

Densities of Milled and Unprocessed Refuse Cells

Cell	Refuse Volume (yd.^{3})	Cover Volume (yd.^{3})	Total Volume* (yd.^{3})	Refuse Wet Weight (Tons)	Refuse Dry Weight (Tons)	Refuse Density** (lbs./yd.^{3})		Effective Density*** (lbs./yd.^{3})		Compaction Time (Hrs.)		
						Wet	Dry	Wet	Dry	Refuse	Cover Dirt	Total
1	1992	286	2224	1114	806	1119	810	1000	724	21.96	2.58	24.54
2	1598	130	1689	1139	745	1425	934	1349	883	21.96	1.75	23.71
3	1938	154	2023	1236	779	1278	804	1210	768	12.33	1.80	14.13

* Total volume does not equal the sum of the refuse volume and cover volume due to further compaction of the in-place refuse as cover dirt was applied and compacted, and also because of sifting of cover dirt into the refuse.

** $$\text{Refuse Density} = \frac{\text{Weight of Refuse}}{\text{Volume of Refuse}}$$

*** $$\text{Effective Density} = \frac{\text{Weight of Refuse}}{\text{Volume of Refuse + Volume of Cover}}$$

TABLE 35

Percent Increase or Decrease of Densities Obtained Using Cell I as a Base

Cell	Wet Refuse Density (lbs/yd^3)	Percent Increase or Decrease from Cell I	Dry Refuse Density (lbs/yd^3)	Percent Increase or Decrease from Cell I	Wet Effective Density (lbs/yd^3)	Percent Increase or Decrease from Cell I	Dry Effective Density (lbs/yd^3)	Percent Increase or Decrease from Cell I
1	1119	0.0	810	0.0	1000	0.0	724	0.0
2	1425	+27.4	934	+15.3	1349	+34.9	883	+22.0
3	1278	+14.2	804	-0.7	1210	+21.0	768	+6.1

An examination of Tables 34 and 35 reveals that, while using approximately the same refuse compaction time, the in-place density of the milled refuse Cell II was 934 lbs./cu.yd., or 15.3 percent greater than that of the unprocessed refuse Cell I on a dry-weight basis. A comparison of refuse densities for Cells I and III, again on a dry-weight basis, shows that nearly equal densities were obtained while only 12.33 hrs. of refuse compaction were used on milled Cell III compared to 21.96 hrs. on the unprocessed refuse cell.

Further comparisons using dry effective densities indicate that Cell II had an effective density of 883 lbs./cu.yd., or 22 percent greater than Cell I. Comparing Cells III and I, milled and unprocessed refuse respectively, a 6.1 percent increase in dry effective density was evident for the milled cell. This increase becomes more significant when it is realized that total compaction time on Cell III was 14.13 hrs. compared to the 24.54 hrs. used on Cell I.

An examination of the figures for density and compaction effort for Cells II and III is also very interesting. For instance, dry refuse density of Cell II was increased only 16.2 percent even though the refuse in Cell II was compacted 78 percent longer than that in Cell III. A similar result is evident when dry effective densities are compared. The dry effective density of Cell II increased only 11.5 percent even though the total compaction time used on Cell II was 68 percent greater than that used on Cell III.

CONCLUSIONS

The controlled density tests as described in this section have revealed the following facts concerning the landfilling of unprocessed refuse vs. the landfilling of milled refuse:

1) Utilizing approximately equal compaction times, a milled refuse cell showed a 15.3 percent increase in refuse density and a 22 percent increase in effective density over an unprocessed refuse cell on a dry-weight basis.

2) Approximately equal dry refuse densities and dry effective densities were achieved in a comparison of a milled refuse cell and an unprocessed refuse cell when the unprocessed refuse cell was compacted an average of 76 percent longer than the milled refuse cell.

3) Test results revealed that dry refuse densities of two milled refuse cells differed by only 16.2 percent even though one cell was compacted 78 percent longer. Dry effective densities of the same two cells increased only 11.5 percent even though one cell was compacted 68 percent longer than the other.

4) Test results indicate that milled refuse required approximately 50 percent less cover dirt than unprocessed refuse to achieve the same degree of cover; in this case complete covering of the refuse.

V. VECTORS

V-A - Rat and Fly Tests at Madison

INTRODUCTION

The casual observer might expect that the practice of leaving refuse uncovered for extended periods of time would result in vector problems. Experience in other countries, however, indicates that vector problems do not result if refuse is milled prior to landfilling. To confirm these findings, field and laboratory studies of flies and rats associated with milled and unprocessed refuse were undertaken.

It would be difficult, if not impossible, to prove that vector problems would never arise using uncovered milled refuse. Vectors will live and/or feed in the best location they can find. This means that the results of any one test will depend on which alternatives are available to the vectors. Therefore, the surrounding area must be considered as part of the test site, and this makes projections to other localities very difficult. Additional complications arise due to climatic conditions, history of the test site, and changes in vector populations. Experience gathered during a comprehensive study of potential vector infestation at Madison is summarized in this report.

Unless noted otherwise, the tests to be described were conducted at the Olin Avenue Landfill in Madison. Over 20 cells of milled refuse which were not covered, or unprocessed refuse covered with a minimum of 6 in. of dirt in the usual sanitary landfill manner, were constructed at the test site (Table 36 and Figure 40). The cells were rectangular and approximately 40 ft. in the smallest dimension. They were 5 to 6 ft. high, and were constructed entirely above grade. All cells were similarly compacted with a D-7 Caterpillar Tractor; however, this compaction of milled material was almost incidental since high compaction was achieved during distribution of material on the cells. All cells were constructed with domestic refuse.

RAT STUDIES

PROCEDURE

Initial studies were designed to compare the attractiveness to rats of milled refuse left uncovered and unprocessed refuse

TABLE 36

Summary of Cell Construction

	TYPE OF CELL*				
Cell Number	Milled	Unprocessed	Material	Construction Dates	Remarks**
1	X		Refuse	Fall, 1967	
2	X		Refuse	"	
3	X		Refuse	"	
4 a and b		X	Refuse	"	
5	X		Garbage	Winter, 1968	Initially, uncovered, later sides were covered.
6		X	Garbage	"	
7	X		Rubbish	"	
8		X	Rubbish	"	
9	X		Refuse	"	
10	X		Refuse	"	
11	X		Refuse	"	
12		X	Refuse	"	
13	X		Refuse	"	
14		X	Refuse	"	
15	X		Refuse	Spring, 1968	
16	X		Refuse	"	
17	X		Refuse	"	
18		X	Refuse	"	
19	X		Refuse	Summer, 1968	
20	X		Refuse	"	
21	X		Refuse	"	
22		X	Refuse	"	

* Combined refuse is garbage plus rubbish as is normally collected. Garbage and rubbish were specially collected for test purposes.

** Except as noted, all milled cells were uncovered and all unmilled cells were covered with at least 6 inches of dirt.

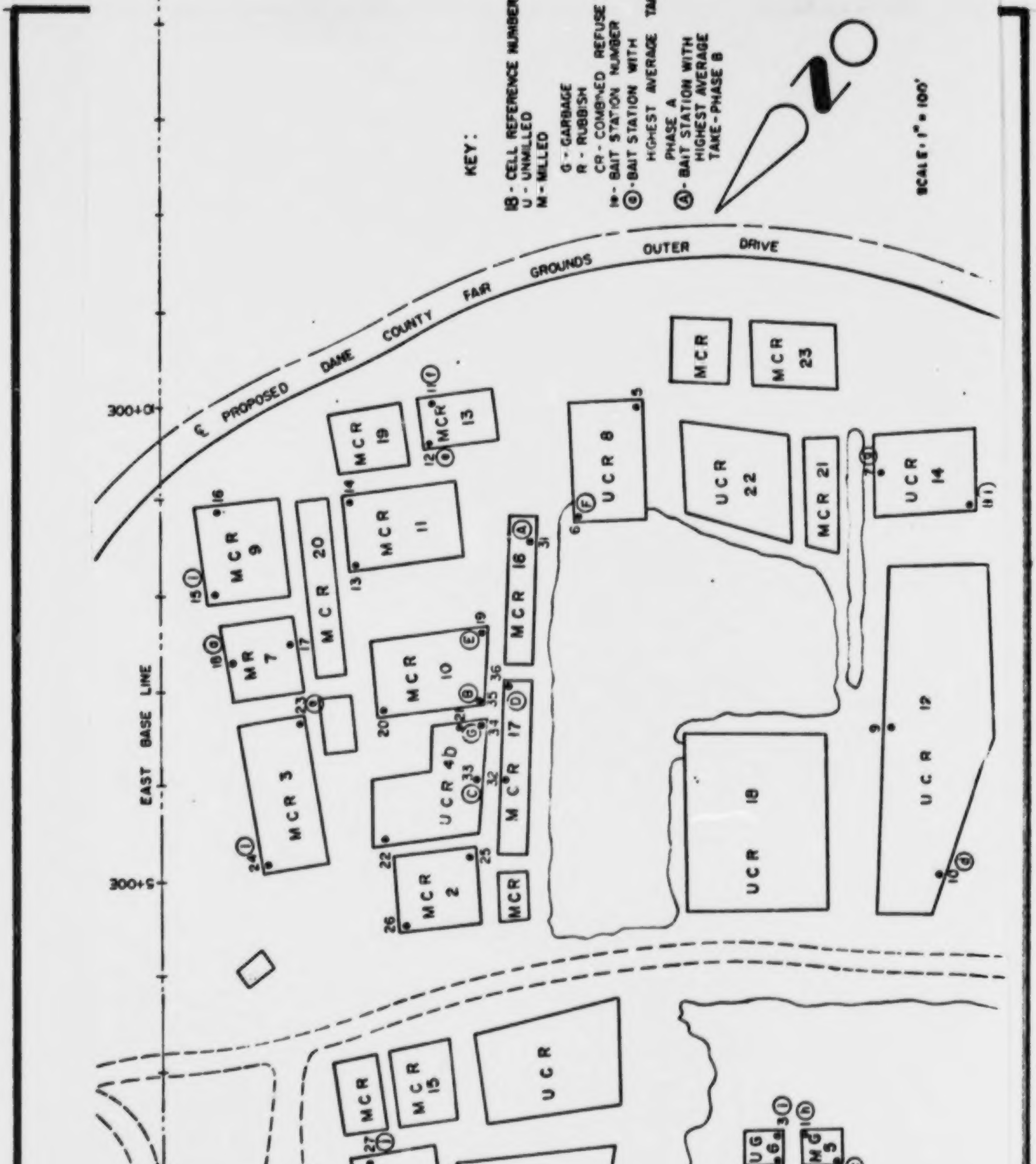

KEY:
18 - CELL REFERENCE NUMBER
U - UNMILLED
M - MILLED
G - GARBAGE
R - RUBBISH
CR - COMBINED REFUSE
16 - BAIT STATION NUMBER
Ⓑ - BAIT STATION WITH HIGHEST AVERAGE TAKE - PHASE A
Ⓐ - BAIT STATION WITH HIGHEST AVERAGE TAKE - PHASE B
N
SCALE: 1" = 100'
PROPOSED DANE COUNTY FAIR GROUNDS OUTER DRIVE
EAST BASE LINE
SOUTH BASE LINE
WINGRA CREEK
300+00E
300+5+00E
3+00 S
0+00 S
MILL
MCR 1
UCR 4a
MCR 15
MCR
UCR
UG 6
MG 5
MCR 2
MCR 3
UCR 4b
MR 7
MCR 9
MCR 20
MCR 11
MCR 10
MCR 17
MCR 16
MCR 19
MCR 13
UCR 8
UCR 18
UCR 22
MCR 21
UCR 14
UCR 12
MCR 23

Figure 40. Cell and Bait Station Map

covered with dirt. By intermixing the two basic cell types throughout the test area, effects of the surrounding environment were minimized.

Of the variety of tests considered for evaluating the relative activity of rats on a given type of cell, bait consumption was chosen as the primary test for the field studies. If identical bait stations are located uniformly about an area, those stations showing increased bait consumption should indicate particularly active spots within the area. The basic assumption is that the stations are equivalent as far as the rat is concerned, so it must make its own choice where to burrow, eat, and scavenge based on merits beyond the presence of a station, of one location over another.

Disadvantages of this method include possible changes in rat habits when food and water are readily available, and the difficulty of separating rat activity from that of birds and other animals. Advantages of the bait consumption method include low cost and ease of operation.

Sightings of rats by project personnel, evidence of feeding (as on gourds growing in the area), development of paths, and the number and apparent activity of burrows are readily observable indicators of rat activity. Such sightings were used throughout the study to supplement the findings obtained by bait consumption.

Thirty bait stations (Figures 40 & 41), holding up to 6 lbs. of bait and 1 qt. of water, were placed as uniformly as possible over the landfill area as shown in Figure 40. Since rats tend to stay in one place and use the same trails, each station was placed near signs of rat activity, if such signs were available within a general area. The bait consisted of 62.5 percent cracked corn, 18.75 percent wheat, 18.75 percent rolled oats, and 3.12 gal. of peanut oil per 1,000 lbs. bait. No poison was used.

The bait containers were weighed regularly to determine the amount of bait loss. Visual evidence of activity was also recorded, such as rat or other droppings, feathers, and wet or scattered bait (the latter signs suggesting the presence of birds or gophers). New burrows or changes in activity around older burrows were also noted. These data were supplemented by a night sighting, as well as placement of two piles of milled refuse, without cover, in isolated areas to determine if rat activity would be drawn to them.

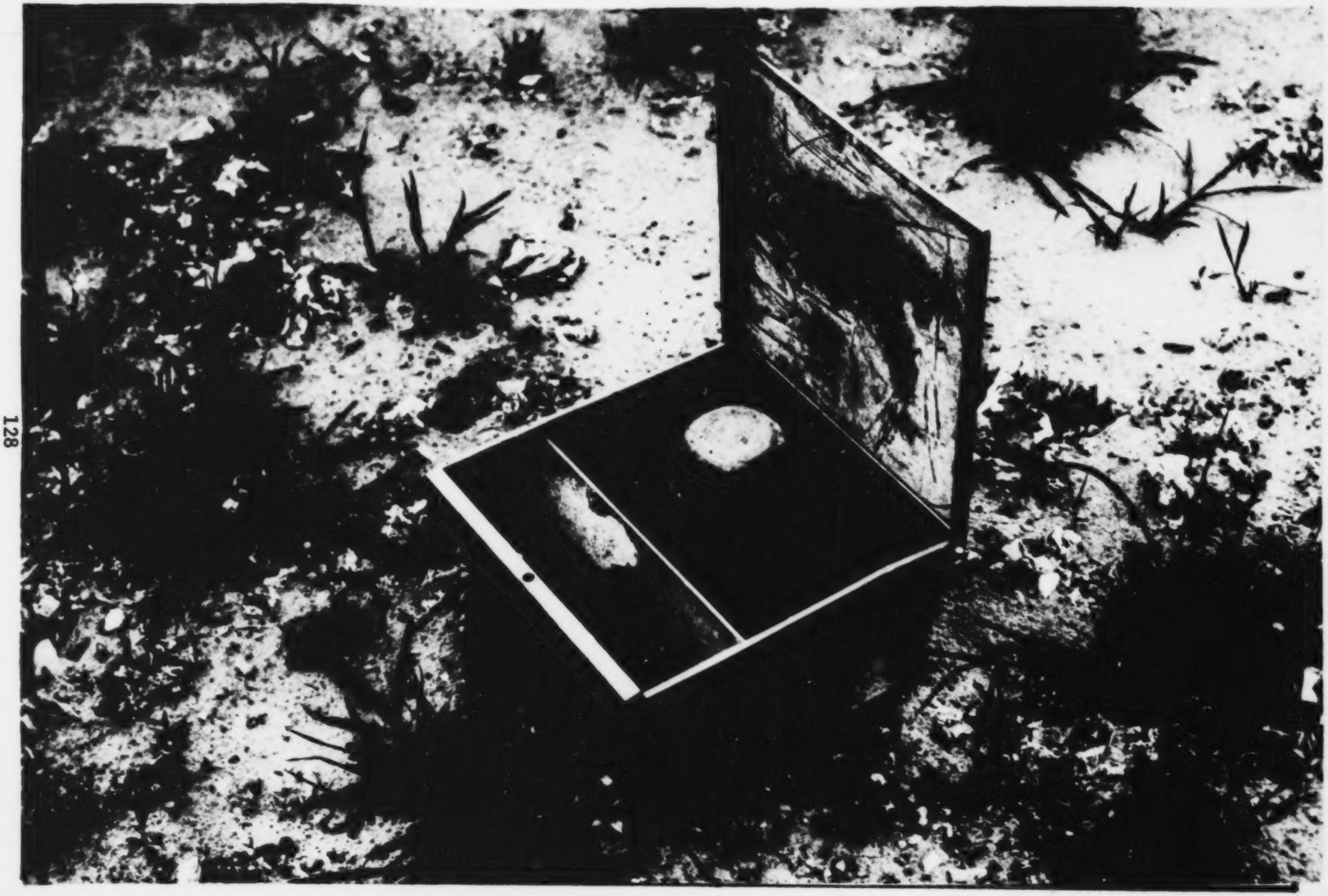


Figure 41. Bait Station Used During Rat Study Phase of Vector Investigation at Olin Avenue Site

RESULTS AND DISCUSSION

The test was divided into three phases, as follows:

Phase A:

Bait stations for this phase were approximately evenly distributed throughout the 20 cells. This test was designed to reveal initial areas of rat activity, as established prior to the testing program. The data were recorded for presentation as shown in Table 37 , where bait consumption for each weighing of each station, several average values for consumption from each station, and visual observations in and near each station are tabulated. There was some concern about changes in levels of rat activity on the various cells due to presence of the bait stations. The different averages were tabulated in an attempt to indicate whether such shifts occurred. The averages for the first 40 days, the last 30 days, and the entire 70-day period of this phase were tabulated for this purpose. An additional value termed the "corrected average" emphasized later readings if a definite trend was observed.

There were several problems in analyzing the data. First, it is possible that bait consumption was not proportional to rat activity at a given location. Also, animals other than rats may have been using the stations. Some rats may have been getting a larger portion of their food from the stations than other rats. Perhaps rats lived on one cell and simply traveled to a spot which they would not normally visit to feed at a bait station. Recording visual signs of activity was a valuable aid in meeting these potential problems, since observations made it possible to determine whether a given station was frequented by rats and whether these rats were living and rummaging on that particular cell. Further, it was pointed out by project consultants that rats eat very little food each day, and that many of their activities are designed not so much for feeding (assuming a minimum amount of food is readily available) as to satisfy their natural impulse to scavenge. Therefore, the preference of one cell type over the other for rummaging and burrowing should not be affected by the presence of attractive bait at several nearby locations.

A second major problem was the possibility that the presence of a bait station was drawing activity to a given cell. Trends in bait consumption rates with time would be important in revealing whether this potential problem existed. For this reason the average

TABLE 37

Example of Tabulation of Results of Phases A, B, and C

Box No.	Cell Type	Daily Wt. Bait Consumed from A to B A_1-B_1 A_2-B_2.... A_n-B_n	Average Consumption from A_1 to B_n	Weighted Average*	Sightings Rats Drop. Other**	Burrow Counts

(For Phase C add column showing rate of decrease in consumption)

* Emphasizes later readings if definite trend is observed

** Indications that other animals were frequenting stations consumptions at each station for the first and last portions of Phase A were tabulated and ranked from the highest to the lowest. Although there was a definite trend at all stations toward increased take, the ranking of the stations remained essentially constant. This supports the conclusion that population growth and increased dependency on the bait occurred throughout the test area, but that little movement from one location to another resulted from the bait stations. The "corrected average" column lists average takes for each station, modified to emphasize trends in the take as well as visual observations. Due to the lack of movement from one station to another during the test, and the fact that initial take rates were small and subject to error, the adjusted readings are emphasized (Table 38).

Table 39 shows the ranking of the bait stations from the greatest to smallest rate of bait consumption. Note that there appears to be no preference between cell types. The highest takes observed in this study occurred in bait stations located on cells constructed of garbage. Since this was an obvious attractant, and since there was much rat activity apparent on these cells, the high take rates substantiate the validity of the test procedure.

The ranking of stations from the highest take downward is also noted on the map of cells, Figure 40 . The highest takes occurred around the periphery of the landfill, leading to the conclusion that the desire of the rats to locate near the periphery of the site was greater than their preference for either milled or unprocessed refuse cells.

It should be noted that on one occasion ten people were stationed in eight cars around the landfill from dusk to midnight. At half-hour intervals headlights were turned on for 30 seconds and the rats counted. Results were disappointing in that few rats were seen; however, those rats that were seen were concentrated in areas where the bait stations had the highest take.

Phase B:

The purpose of Phase B was to test the validity of the previous results by moving the stations to new locations. If the stations did not draw activity with them, the consumption rates from Phase A would apparently reflect the desirability of the location of each station. If, on the other hand, the stations did draw activity, the rats could be forced, through appropriate station placement, into chosing among the various new locations available to them, each of which

TABLE 38

The Results Of Phase A

Cell[1] Const./ Box No.	Daily Weight of Bait Consumed Over Period from A to B A/B															Average[2]				No. of Sightings		
	4-9 / 4-11	4-11 / 4-26	4-26 / 4-29	4-29 / 5-5	5-5 / 5-10	5-10 / 5-13	5-13 / 5-17	5-17 / 5-21	5-21 / 5-25	5-25 / 5-31	5-31 / 6-5	6-5 / 6-11	6-11 / 6-17	6-17 / 6-19	6-19 / 7-3	4-9 / 5-21	5-21 / 6-17	4-9 / 6-17	Corrected[4]	Rat	Rat Drop	Other[3]
MCR/27	-		.08		.05	.10	.06	.04	.11		.07			.04	.20	.05	.09	.06	.08		6	3
MCR/28		.04*	.01		.09		.33							.09	.09	.14		.14	.12	2	1	7
MCR/25						-		-								.00		.00	.00			2
MCR/26						-		-						.15		.00		.00	.00			3
MCR/23		.03*	*		.08	.09		.12		.19	.14*					.10	.19	.12	.18	1	3	3
MCR/24	.04				.09	.12		.04								.07		.07	.10	3		6
UCR/29	.01	.01			.06	.08	.05	.05			.08			.16	.14	.04	.08	.05	.15	3	1	1
UCR/30	.03	.02*			.23	.19	.16	.11	.17	.35	.38			.38		.14	.30	.20	.38	6	3	2
UCR/21	.02															.02		.02	.02			6
UCR/22						.01		-								.01		.01	.01			5
MG/1		.03*				.21	.14	.13			.13			.08		.16	.13	.15	.12	3		
MG/2	.02	.03*		.15	.35*		.58	.51	.45		.35	.46				.32	.42	.36	.36	6		4
UG/3							.01	-						.04		.01		.01	.03			1
UG/4						.01		.10			.14			.17	.16	.05	.14	.08	.17	5		2
MR/17			-	-	-	.07										.02		.02	.03			5
MR/18			-	.06	.12					.23	.12*	.55	.77*			.06	.39	.19	.45	6		4
UR/5					.02			.06							.12	.04		.04	.04			7
UR/6		.01			.04										.05	.02		.02	.01			7
MCR/15				.02	.18											.10		.10	.10			8
MCR/16			-		-	.04		-								.01		.01	.01			6
MCR/19																						
MCR/20			-			.02										.01		.01	.01			4
MCR/13			.01			.02	-	.01								.01		.01	.01			7
UCR/14			.01			.01		-								.01		.01	.01			5
UCR/9						.07		-			.01	.14		.13		.04	.07	.05	.05			1
UCR/10												.20			.32*		.20	.20	.20			7
MCR/11			-					-			.17				.16	.00	.17	.06	.17			7
MCR/12					.06		.11			.17*	.20				.16	.09	.20	.12	.18		1	7
UCR/7						-		.02				.15				.01	.15	.06	.15			3
UCR/8			.13		.07									.20	.32*	.10		.10	.10			9

- Essentially no take.

* Empty, therefore indicated value is a minimum.

1 M=milled, U=unprocessed, R=rubbish, G=garbage, CR=refuse = rubbish + garbage

2 The last two readings are not included in the averages to show how well the averages represent future activity.

3 Other means birds, gophers, scattered bait, wet bait, or other indications that animals other than rats were frequenting the station.

Note: If no value is recorded, this normally means that the bait was wet or scattered.

4 The corrected average emphasizes later readings if a definite trend is observed.

would have an identical bait station. This choice would then be based on considerations other than the presence of a bait station and would reflect the desirability of the site.

Since previous results indicated that most activity was around the periphery of the landfill, nearly all of the peripheral stations were removed for Phase B, and nine stations were placed or allowed to remain in the central area of the fill, where previously there had been neglible activity. The results were reported in a table similar to that shown for Phase A, except only one average was necessary since there were no obvious trends in the data with time (Table 40). The lack of such trends suggests that, whereas in Phase A the rats were initially not dependent on the bait, such a dependency was well established by the time Phase B began.

TABLE 39

Rank of Daily Average Consumption According to Cell Type

	MILLED	UNPROCESSED
	1**	-
	-	2
↑	3	-
Increasing	-	4*
Take	5,6	-
	7	8
	-	9*,10
	11,12	-
	13,14	15*,16*
	17	-

* Possibly an error from scattering.

** Milled garbage, not covered. Take dropped sharply when sides were covered.

Table 40 Results of Phase B*

		Daily Weight of Bait Consumed Over Period from A to B $\frac{A}{B}$											Sightings			
Box No.	Cell Const.	7-3/7-8	7-8/7-11	7-11/7-14	7-14/7-18	7-18/7-22	7-22/7-26	7-26/7-29	7-29/8-2	8-2/8-6	8-6/8-9	Average Take	Rat	Rat Drop	Other	No. of Burrows
24	MCR							.42				.42				
3	UG			.23			.62	.86	.74			.61				
18	MR	.87						.65				.76				
19	MCR			1.41?			.92	.63	.98	.98	1.29	.96			2	5
35	MCR						.59	1.32	.97	.95	1.33	1.03			2	1
6	UR			1.18?	.81	.85?		.49				.65		2	4	2
31	MCR		1.42	.71?		.69?	1.07	1.34	.70		1.29	1.16	1		1	
33	UCR						1.01					1.01			7	
34	UCR	.80?	.16				.20	.46	.70	.09		.29	1			7
32	MCR	.17?										.17?			7	
36	MCR						.94	.77		1.01	1.27	.99			3	

? Questionable results - usually because of a fair amount of scattering which was not enough to cause complete rejection of the data.

* See bottom of Table 38 for definitions of terms or markings.

Results show that rat activity was drawn readily for distances up to 100 ft. and that many of the original burrows were retained while the rats simply moved to the new station locations for feeding. In addition, there was some drawing of rats into the central area of the landfill from distances up to 400 ft. This migration led to much test drilling, resulting eventually in 18 new burrows. Of these, 12 were on the two unprocessed, covered cells in the central area; the remaining six were on one of the four milled, uncovered cells in this area. Thus, it appears that the unprocessed, covered cells provided better drilling and living conditions than did the milled cells.

The fact that rats were drawn by the stations in Phase B does not negate the results from Phase A, for by the time Phase B was initiated the rats were unnaturally dependent on the bait and were willing to search for it. It should be noted that because of problems associated with the presence of birds and other animals during this phase, the bait consumption data were difficult to interpret; therefore the visual observations were emphasized in reaching conclusions for Phase B.

Phase C:

The last phase of the testing program consisted of adding poison to the bait and observing the rate of kill. The practice of using bait for several weeks to acclimate rats to a bait station, before adding poison to the bait, helps produce an effective kill. To assure a thorough kill, the bait stations were moved back to their original locations and nonpoisoned bait was used for almost 3 weeks prior to poisoning. Three to 9 days after the addition of 5-percent-by-weight anticoagulant rodenticide to the bait, the kill was essentially complete. The rate of decrease of bait take was higher on the milled refuse cells and lower on the unprocessed cells. This may suggest that rats frequenting the milled cells were more dependent on the bait than were rats associated with unprocessed cells (Table 41).

Table 41 - Results of Phase C*

Box No.	Cell Const.	Daily Weight of Bait Consumed 8-26 / 8-29	8-29 / 9-3	9-3 / 9-5	9-5 / 9-17	9-17 / 9-27	Rate of Decrease in Consumption 8-26 to 9-27	8-29 to 9-27	9-3 to 9-27
27	MCR	.26		-		-	.0081	.0003	0
28	MCR	.02	.01	-	-	-	.0006	.0003	0
25	MCR	.64	.47	.25	.02	.01	.0197	.0158	.0100
26	MCR	.35	.07	.01	.02	.01	.0106	.0021	0
23	MCR	.27	.13	-	-	.06	.0066	.0024	-.0025
24	MCR	.63	.19	.22	.23	.02	.0191	.0059	.0083
29	UCR								
30	UCR	-	-	-	-	-	0	0	0
21	UCR	.05	.01	-		.01	.0012	0	-.0004
22	UCR	.10	.14	-		.04	.0019	.0034	-.0016
1	MG	.14		.04		.01	.0041		.0012
2	MG	.05	.01	.10	.01	.01	.0012	0	.0038
3	UG	.32	.14	.36		.02	.0094	.0042	.0142
4	UG		.08	-	.01	.01		.0024	-.0004
17	MR	.63	.34	.05	.04	.02	.0191	.0110	.0012
18	MR	.34	.07	.11	.04	.01	.0103	.0021	.0042
5	UR	.07	-	-	-	-	.0022	0	0
6	UR	.04	-	-	-	-	.0012	0	0
15	MCR	.01	.01	.03	.06	.10	-.0028	-.0031	-.0029
16	MCR	.09	.34	-	.08	.05	.0012	.0100	-.0021
19	MCR		.40	.26	.14	.03		.0128	.0096
20	MCR	.01	.01	.02	-	-	.0003	.0003	.0008
13	MCR	-	.08	-	.04	.01	-.0003	.0024	-.0004
14	MCR	.21	.14	.39	.25	.02	.0059	.0042	.0152
9	UCR	.02	-	-	-	-	.0006	0	0
10	UCR	.01	.01	-	-	-	.0003	.0003	0
11	MCR	.01	.05	-	-	-	.0003	.0017	0
12	MCR	.57	.30	.10	.10	.07	.0156	.0079	.0012
7	UCR	-	-	-	-	-	0	0	0
8	UCR	.01	.02	-	-	-	.0003	.0007	0

* See bottom of Table 38 for definitions of terms or markings.

Some General Observations:

The bait consumption method was found to provide meaningful results in comparing the attractiveness to rats of the two basic cell types. It was found useful, however, to substantiate these results with visual observations recorded during bait-replenishing tours and during special tours taken solely to count burrows, to observe paths and other signs of activity, and to determine whether such activity was recent. Although simple bait consumption was found to correctly indicate areas of activity in this case, it is suggested that problems due to birds, other animals, wet or scattered feed, etc. may make results difficult to interpret if visual observations are not recorded.

It was noted that any irregularity in the surface of a cell, whether milled or unprocessed, was likely to lead to test drilling or a burrow. A large object such as a rock, part of a tree, or a chair, if placed at or near the surface of a cell, will disrupt the uniformity of the surface or provide a break in the surface, making that spot desirable for drilling. In this respect the covering of cells can be detrimental, for erosion of the cover provides surface irregularities which may lead to test drilling.

Note further that with milled, uncovered cells a break in the surface is not as likely to result in burrows as a comparable break on an unprocessed, covered cell. With milled cells the interior offers only more of the same material as is encountered at the surface, so a break is not necessarily conducive to extensive burrowing. In unprocessed cells, however, when the cover material has been penetrated, rats can develop long paths, make nests, and rummage for food without difficulty.

In general, more burrows were found on unprocessed, covered cells than on milled, uncovered cells. Possible reasons for this include the ease of finding food in unprocessed refuse as opposed to milled, in which edible matter is ground into relatively small pieces and distributed among nonedibles. The uniformly small particles may also impair the drilling qualities of milled refuse; for example, there would be litttle opportunity for burrowing under larger objects to strengthen the ceiling of a tunnel in milled refuse. Another reason may be the obvious futility of burrowing in milled refuse, for, as drilling proceeds, only more of the same homogeneous material is encountered. Most of the signs of test drilling without burrow development were found on milled cells.

Construction of Special Test Cells in Remote Locations:

The field studies suggested that milled refuse without cover was no more attractive, and probably less attractive, to rats than was unprocessed refuse covered with earth. It remained to be shown, however, whether milled refuse by itself would attract rodents. To determine this, several tons of milled refuse were placed in a remote location within a Madison residential area. The site was fenced to keep out domestic animals and people, after which it was checked periodically for signs of rodent activity. No activity was observed after several months, and the test was terminated.

The above test could not be considered conclusive in itself, for there was no assurance that rats were living in the area, nor was there any reason to expect any rats nearby to leave their previous surroundings in favor of milled refuse. Consequently, a similar pile of milled refuse was placed in a remote location at the Olin Avenue Landfill where rats were known to be present. After several months no signs of activity were observed, and the test was terminated. Note again, however, that the results are not necessarily applicable to other locations. Depending on other sites available to the rats, and whether nearby rat colonies have grown to the point that these other sites are saturated, the results of this test must be subject to some uncertainty.

CONCLUSION

It is felt that the combination of field tests described above provides rather conclusive evidence that milled refuse of a composition found in Madison will not result in rat infestation at a landfill. The fact that no rats have been sited at the landfill in the 2 years since the rats were poisoned, and that a mother duck has felt sufficiently secure to develop a nest and lay eggs near the center of the site, supports the findings of the study.

FLY STUDIES

The testing program to evaluate potential fly problems which might from not covering milled refuse consisted of the following parts:

(1) an evaluation of the relative numbers of flies present on or near uncovered milled and covered unprocessed refuse cells;

(2) studies in which flies emerging from refuse in large cages were counted;

(3) laboratory studies to determine whether flies could live and reproduce on milled refuse; and

(4) tests to determine the survival rate of maggots in refuse passing through the mill.

Each of these studies will be considered separately. Note that the latter three studies were undertaken by the Department of Entomology at the University of Wisconsin-Madison under a special contract with the project.

FIELD STUDIES ON RELATIVE ATTRACTIVENESS

A comparison of the relative numbers of flies found on or near the two types of refuse cells was made in much the same manner as was done with rats. Such a comparison was necessary to show whether the practice of not covering milled refuse would result in more or less fly problems than found in sanitary landfills of standard construction and acceptable with respect to fly densities.

A Scudder Grille (Figure 42) was used to determine the fly population. The grille was made of 1/4 x 3/4 in. slats, 3 ft. long, placed parallel and 3/4 in. apart on a frame. By providing many edges, the grille makes use of the flies' habit of landing near an edge. The procedure for this study was to place the grille on a cell and, after 30 sec., count the number of flies on the grille. Normally this procedure was repeated six times for each cell. Since results were dependent on the weather, counts were made only on sunny days with temperatures near 80° F. and wind velocities less than 5 mph.

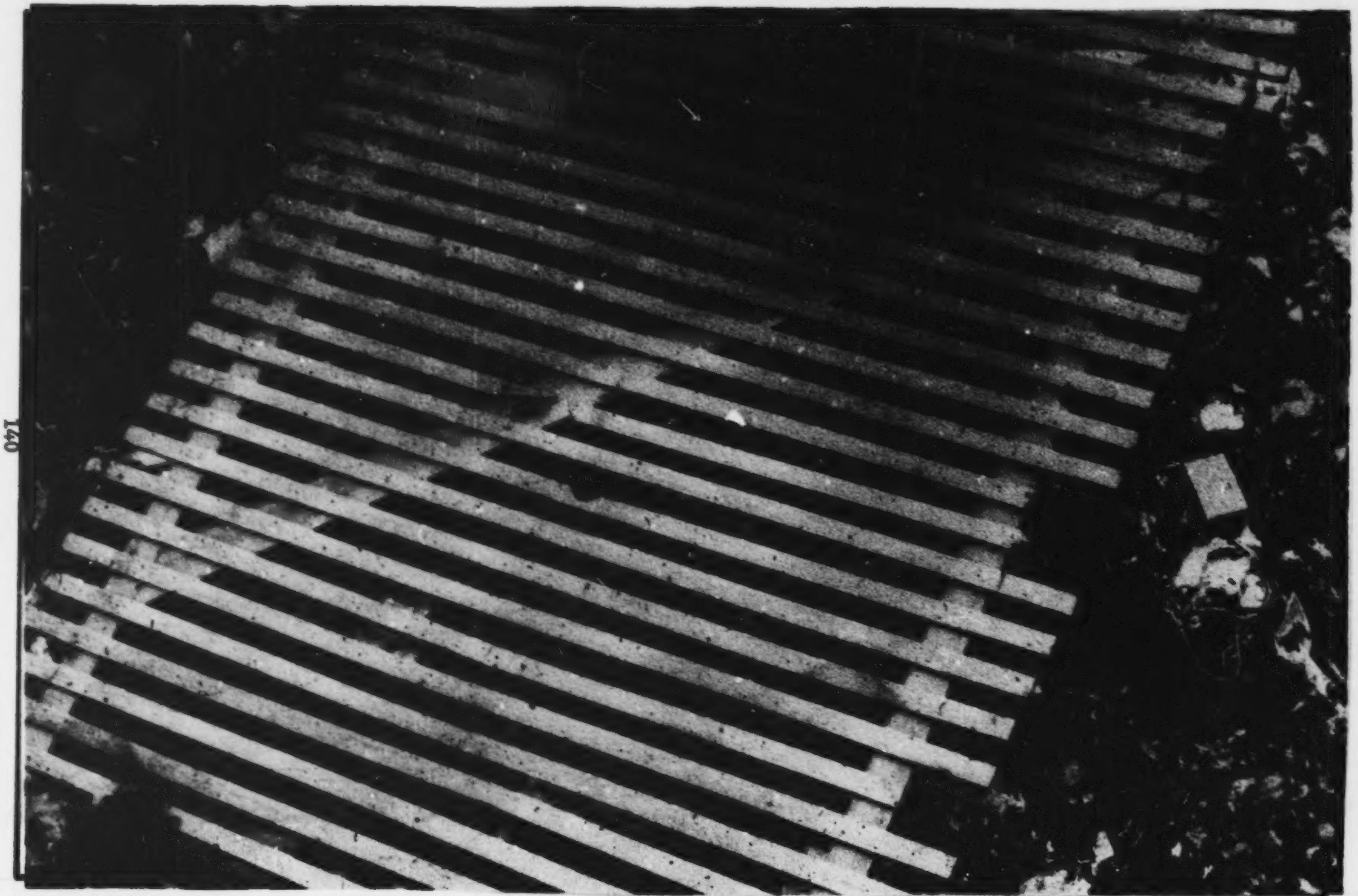


Figure 42. Scudder Grille Used to Estimate a Number of Flies on Milled and Unprocessed Refuse

The results, as summarized on Table 42, indicate no marked differences in the number of flies on milled or unprocessed cells. The highest counts were obtained on milled uncovered fresh refuse and on the two garbage cells; the lowest counts occurred with uncovered milled refuse.

TABLE 42

Average Number of Flies Counted Per Observation

Observations made weekly over two month period.
Each observation includes 4 to 5 counts per cell.

AVERAGE NUMBER COUNTED	
MILLED	UNPROCESSED
5.0*	-
-	2.8**
-	2.3***
1.2**	-
0.8	-
0.7	-
0.6	0.6
0.5	0.5
-	0.4,0.4
0.3,0.3	-
0.2,0.2	0.2,0.2
5 cells ≤ 0.1	no cells ≤ 0.1

* garbage, not covered

** under construction during counting period

*** garbage, covered

Portions of various cell surfaces were examined for fly larvae to determine the ability of flies to live on the cells. Few larvae were found and no significant differences were noted between milled and unprocessed cells in this respect.

EMERGENCE STUDIES

These studies were designed to determine the numbers of flies emerging from comparable amounts of milled and unprocessed refuse. One-half of a load (approximately 2 tons) of residential refuse was placed on flat ground and compacted with a D-7 Caterpillar tractor. Another load of comparable refuse was milled and then placed in two equal portions and similarly compacted. Screened cages measuring 10 x 10 x 6 ft. high (Figure 43) were placed over each of the three refuse piles and the flies in each cage were counted periodically over the one month duration of the test.

The results are shown in Table 43 . Cage 1 contained the unprocessed refuse and had significantly more flies over the period of the experiment than did cage 3, which contained milled refuse. Cage 2 also contained milled refuse and was identical to cage 3 until the 12th day, when 1,200 adult flies and 2,000 maggots were added to the refuse. This was done to determine whether the lack of flies emerging from milled refuse was due to the lack of viable flies or maggots in the refuse, or to the inability of milled refuse to support flies. The data indicates that flies were able to survive on milled refuse, but that maggots were unable to complete their life cycle and thus did not produce more flies.

In summary, the cage tests indicated that very few flies emerged from milled refuse as compared to unprocessed refuse. Flies were found to be able to survive on milled refuse, but maggots could not do so. It remained to show whether the mill provided an extra benefit in reducing fly populations during the grinding process and whether milled refuse could support flies under any environmental conditions.

LABORATORY STUDIES

Samples of fresh and 6-month-old milled refuse were used for laboratory studies to determine whether this material could support flies. The material was placed in four cartons (two fresh, two aged) which were covered with cheesecloth. Approximately 1,000 fly eggs were introduced to one carton of each type of refuse. The refuse was moistened with distilled water and the cartons held at 80° F. and a relative humidity of 40 to 70 percent. The test lasted 3 weeks.

Figure 43. Screened Cages Used During Fly Survivability Tests, 1969

TABLE 43

Results of Cage Tests

DAYS	CAGE 1 - UNPROCESSED, COMPACTED	CAGE 2 - MILLED	CAGE 3 - MILLED
0	More flies than cages 2 or 3	---	---
1	~(approx.) 1,000 flies	10 flies	15 flies
6	~1,000 flies	none	none
12	~4,000 flies	1,200 adult and 2,000 maggots introduced	none
15	remaining at large number	~1,000 flies*	none
20	remaining at large number	2 flies**	none
21 on	number began to decline	---	---

* Indicates adult flies survived

** Indicates maggots were unable to complete life cycle to produce more flies, and the initial 1,200 flies died.

With the freshly milled refuse, no flies were observed throughout the test in the carton to which no eggs were added, supporting the cage studies which showed lack of fly emergence from milled cells. In the carton to which the 1,000 eggs were added, approximately 1,000 flies were counted at the end of the 3-week life cycle, suggesting that when milled refuse is properly moistened and is subjected to optimal environmental conditions, it will support flies through the growth cycle.

The 6-month-old refuse evidently contained some maggots and/or eggs, for under the closely controlled laboratory conditions a few flies did emerge. Note that these were not houseflies. These eggs or maggots were probably picked up by the refuse during the 6 months it was part of a milled, uncovered refuse cell at the landfill; they were able to emerge after subjection to the closely controlled laboratory conditions. The aged refuse was not able to support the life cycle of the added eggs, for approximately the same number of flies emerged when compared with the carton to which no eggs were added.

In conclusion, the laboratory study showed that under optimum growth conditions, fresh milled refuse could support the fly life cycle. It is likely that moisture content of the refuse is a particularly critical factor in determining whether the cycle will be completed. Aged refuse was a poor medium for housefly development under optimal laboratory conditions.

SURVIVAL OF MAGGOTS DURING MILLING

It remained to show whether the various forms of fly life are killed in passing through the mill. On two occasions the mill was cleared of refuse momentarily by stopping the feed conveyor. In the first trial 6,000 mature housefly maggots were scattered on perhaps 100 lbs. of refuse on the feeding conveyor, which was started immediately after clearing the mill to simulate the normal passage of refuse through the mill. The second trial was identical to the first except 12,000 maggots were used.

The refuse was collected on a large plastic sheet and examined for living maggots. The refuse was then placed in plastic bags and brought to the laboratory where samples of it were exposed to the proper media and environmental conditions to assure that any maggots which were overlooked would emerge as flies. In the first trial no flies emerged; in the second 84 flies were counted.

It is possible that some maggots were lost in the mill; however, care was taken to avoid this. The most likely explanation for the large decrease in viable maggots is that most of them were macerated during the milling process.

CONCLUSION

The studies described showed that there are several mechanisms by which the fly population at a landfill constructed of milled refuse without cover will be equal or less than that at a sanitary landfill where unprocessed refuse is covered daily with earth. The milling process in itself destroys nearly all forms of housefly life, probably by maceration. Second, freshly milled refuse can support the fly reproduction cycle only under optimum conditions (moisture levels are especially critical) which are not normally obtained in a landfill. Third, once the refuse has aged for several months, even this ability under optimum conditions is destroyed. Finally, field studies suggested that whether the flies originate from refuse or elsewhere, they will be no more, and probably less, attracted to milled uncovered refuse than they will to unprocessed refuse with earth cover.

It is noted that no one of the tests described provides proof that no fly problems will exist with milled refuse; however, when all of the tests are taken together the evidence becomes quite conclusive. Note further that experience at the landfill over 5 years of operation has supported the conclusion of this study, for there have been comparatively few flies reported at the site.

V-B - Rat Studies at Purdue University

BACKGROUND

Field tests and operational experience have indicated that there is no apparent problem with rat infestation of milled refuse landfilled without daily cover. Field tests at the Olin Avenue Landfill led to the conclusion that there was no detectable difference between milled test cells without cover and unprocessed refuse cells with cover soil as far as the presence of rats was concerned. Burrow development was more likely on the unprocessed cells, evidently because of the ease of burrowing and the uneven surfaces due to erosion. Additional tests in which milled refuse was placed in remote locations resulted in no observable drawing of rats.

These tests, coupled with 6 years of experience at Madison during which no rats have been observed on the milled refuse, provide rather conclusive evidence that milled refuse without daily cover does not present any new or unusual likelihood of rat problems on a landfill. The major problem with this conclusion is that it is strictly applicable only to Madison and the conditions of the various tests involved in its formulation.

Cage tests performed at Purdue University were designed to force rats into depending solely on the milled refuse for sustenance. The test results should be absolute in the sense that rats can or cannot survive on milled refuse having Madison's composition. This is in contrast to the field tests and observations of landfills, where one is measuring the relative merits of the milled refuse and other alternatives available to any rats in the vicinity. If, for example, a landfill site is located near a stream, the banks of which are ideal for burrowing, and large quantities of corn are stored in readily accessible bins nearby, the chances are that even an open dump would be less desirable to rats than these other nearly ideal conditions. Of course, over the long term, the rat population would expand to the level which the living conditions could support, in which case the open dump would eventually become infested as well. The point is, however, that the likelihood of a rat population at a given site is dependent not only on the suitability of the site, but also the suitability of alternatives presented by the surrounding area.

In addition to the field and cage studies, the reader is referred to the section on European observations for documentation which should be helpful in assaying potential rat problems at milled refuse sites.

SPECIFIC OBJECTIVES

There were two specific objectives for this study:

(1) determine whether rats can survive on a diet of milled refuse, and

(2) examine the effect of refuse composition on the ability to survive.

PROCEDURE

Purdue University's Rodent Control Fund and the U. S. Department of the Interior maintain a Rodent Test Center at Lafayette, Indiana, primarily for the purpose of testing baits and poisons. This is one of the very few facilities in the country where "wild" Norway rats (Rattus norvegicus) are maintained for test purposes. Approximately 750 rats are kept in 2 large concrete-lined breeding areas, where the rats can burrow and live under nearly normal circumstances until they are trapped for test purposes. Figure 44 is a picture of this outdoor area. All procedures are conducted in accordance with specifications set up by the Rodent Control Fund. The facilities and expertise were obtained on a contract basis for the purposes of this project.

Prime wild Norway rats, each weighing over 200 grams or more, were used for the tests. Five males and 5 females were used in each tank, and all tests were conducted to a logical conclusion or over a 15-day period, whichever came first. Rats were trapped, sexed, weighed, and placed in the test tanks. Whole shell corn and a commercial lab block, plus water, were used in the tanks for a 24-hour period prior to testing. This was done to acclimate the rats to the test tanks by keeping them on the diet to which they are accustomed.

The test tanks were metal, 3 x 7 x 2 ft. high. Each tank was divided by a partition located 30 in. from one end of the tank. The partitions had a 4 x 4 in. opening with a sliding door at the bottom center. A 5-gallon can with one end removed was blocked to stay on its side and was used as a nest box. One such can was placed in the smaller end of each test tank. The portion of each tank containing the next box was covered to darken the area. The animals were contained in this area by the sliding door for cleaning

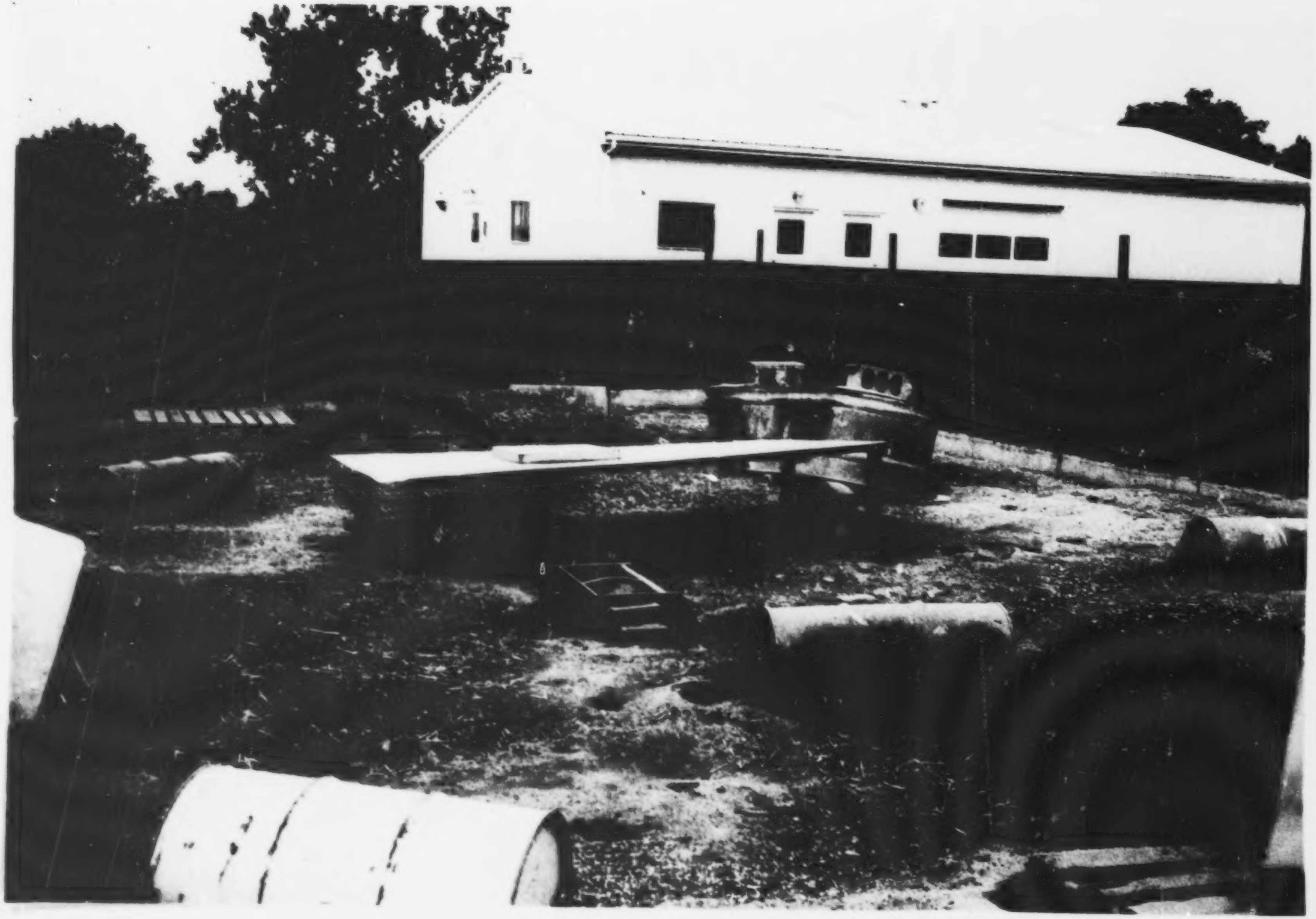


Figure 44. Pen for Norway Rats at Rodent Test Center at Purdue University, Lafayette, Indiana

the other end of the cage and replenishing the feed supply. For the first series of tests, the test tanks were kept inside a building at 70° F. and in total darkness. Because of a lack of space in the building, the last two test series were conducted outside, but during a season of the year when moderate temperatures (reaching in the 70's and 80's daily) were attained. In the outdoor tests the entire test cages were covered to maintain darkness. One of the test cages used is shown in Figure 45.

Three test series were run. In the first series refuse believed to be of "normal" residential-light commercial composition, both freshly milled and aged in the landfill, was used. Specially composited refuse of higher garbage content were used in the second test series, and again in the third series but at much lower and more realistic garbage content than the second series. The procedure was to replace the corn-lab block with the appropriate amount of milled refuse. The refuse was placed in the larger end of each test tank, and then replaced or replenished daily throughout the test period as appropriate. No other source of food was available, although water was available at all times. Each day the rats were observed, and weights were taken when necessary.

ADDITIONAL TEST CONDITIONS AND RESULTS

Test Series I:

Milled samples were taken from what appeared to be typical truckloads of residential-light commercial solid waste. According to the Public Health Service survey of the refuse composition at Madison (see Appendix N), the average garbage content was 15 percent, and this value was assumed valid for the samples sent to Purdue. This material was milled and then promptly placed in metal cans lined with plastic bags. The bags were tied securely and the cans sealed for shipment. Aged milled refuse was also sent in similar amounts to Purdue. This material was dug from Cell III, at that time approximately 2 years old. This milled refuse cell was also assumed to have contained 15 percent garbage.

It was necessary for the purposes of this experiment to be sure that there was sufficient food available in the milled refuse to sustain the rats. The accepted minimum requirement of food for rats is 30 grams of dry "organic matter" per rat per day,

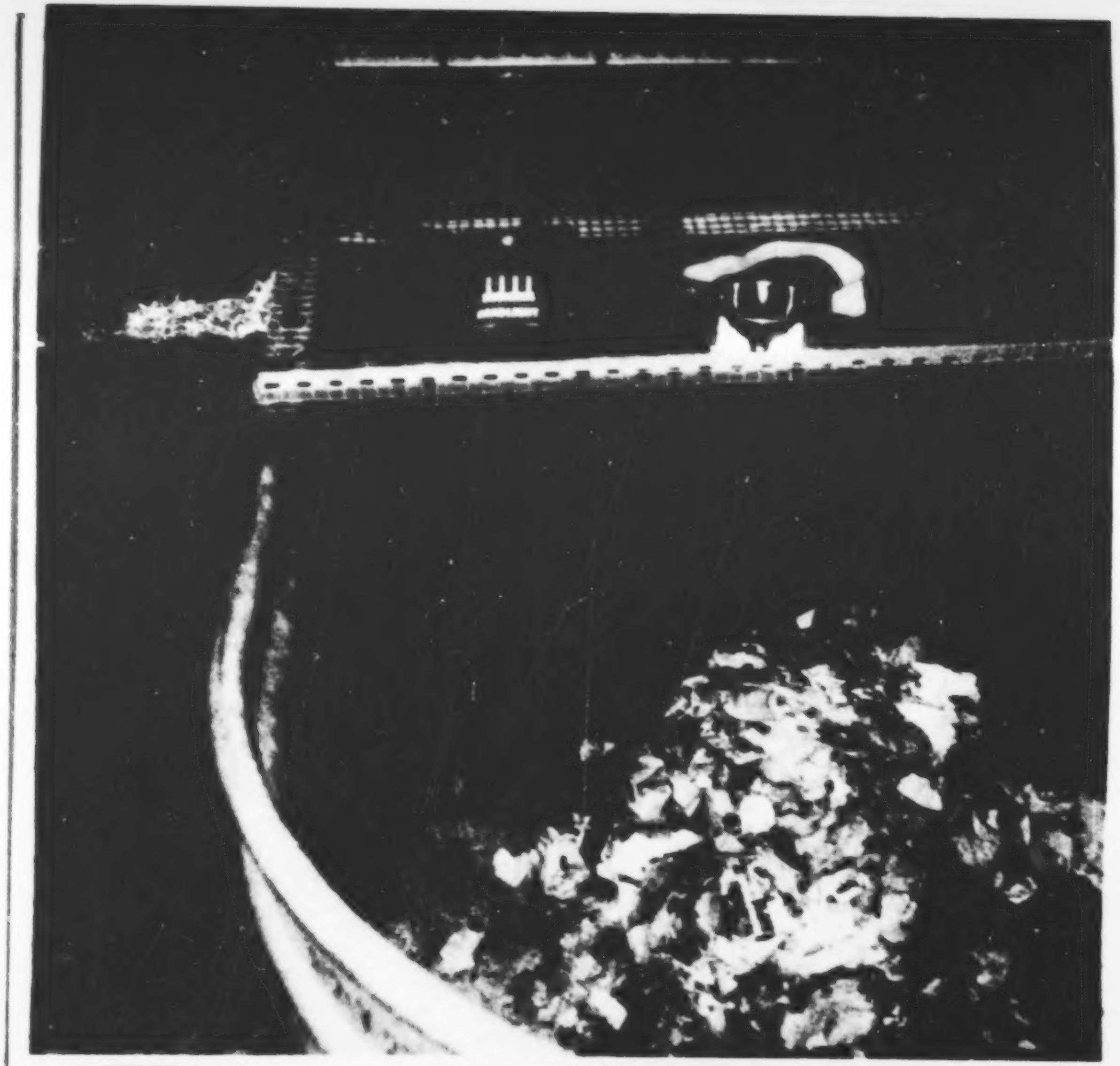


Figure 45. Typical Cage Used in Studies Conducted at Purdue University

where organic matter is defined as edible and able to sustain life for a rat. This definition would exclude paper. It seemed reasonable for a first estimate to assume that the garbage matter in refuse is, in fact, equivalent to the "organic matter" able to sustain rat life. The minimum daily amount of refuse to sustain life may then be calculated as follows:

$$\frac{30 \text{ grams}}{\text{rat}} \times 10 \text{ rats} = 300 \text{ grams}$$

At 15 percent garbage, assumed to be 50 percent water,

$$\frac{300 \text{ grams}}{0.50 \times 0.15} \times \frac{\text{lb.}}{454 \text{ grams}} = 8.83 \text{ lbs./day}$$

Therefore, 8.83 lbs. of milled solid waste per day should contain enough food to sustain 10 rats, but just to be sure, 30 lbs. of this material was actually made available to the rats at any given time. This should have provided over three times the minimum amount of food required to sustain life, thereby allowing for any errors in the above assumptions.

Fresh Milled Refuse

This material was piled to a 20-in. peak with a clear area 15 to 16 in. in front of the partitioned nest area. By approximately 5:00 p.m. each day the rats would move and scatter the material to a height of 8 to 10 in. On the following morning, it would be scattered over the floor area to a more or less uniform level of 3 to 4 in.

Although there appeared to be more food available in the fresh milled refuse than the aged, it was not sufficient to sustain life. Two similar tests were run with this material. During the first test, 2 animals were cannibalized on the eleventh night, one each during the next 2 nights, and 3 more on the fourteenth night. The remaining 3 animals were extremely thin and weak and would have died shortly; however, they were killed on the fifteenth day to terminate the test.

The second test was similar to the first, with 3 animals cannibalized on the tenth night, one during each of the next 3 nights, and 2 on the fourteenth night. Two animals were killed on the fifteenth day; these animals were also very thin and weak.

Aged Milled Refuse

This material was piled to a 5 to 6 in. peak in two 16-1/2 x 1 in. metal pans, leaving 4-1/2 in. on each side and 10-1/2 in. on each end in the feeding end of the test tanks.

This damp, heavy, compact material was picked over first, after which the animals would dig holes and scatter the material in search of food. The rats moved the plastic material into the nest box for bedding.

This test was also run in duplicate. In the first case all animals were showing weight loss by the fourth day. During the fifth night one animal was cannibalized, one on the sixth night, 2 on the seventh night, and one on each of the next 5 nights. The last animal died the afternoon of the sixteenth day.

The second test was almost identical to the first except the last animal was killed at the end of 15 days.

Observations

Animal activity was checked several times a day during all tests. Due to total darkness, the normal feeding behavior was broken. During observation periods, animals were seen searching both types of waste material for food. This would indicate a continued desire for food which was not satisfied from the available material.

During each of the tests there was very little activity the first day. The second day very little change was observed in the aged refuse, but the fresh milled material was scattered. New material was added on the third day to each tank, and daily thereafter.

The conclusion of this test series, applicable to the refuse as received, is that it appears impossible for either freshly milled or aged milled refuse to sustain a rat population. Note that the conclusion does not preclude the possibility of a few rats moving in and out of an area where milled solid waste is deposited.

Test Series II:

The primary objective of the second test series was to evaluate the ability of rats to survive on a diet of milled refuse containing various predetermined fractions of garbage or food wastes. In contrast to Series I, the material used for this test was mixed in the desired proportions from the garbage and nongarbage fractions of residential-light commercial solid waste. The waste had been dumped on a flat surface at the mill, sorted into garbage and nongarbage fractions by hand, mixed into the desired proportions, covered with plastic sheets, and milled the next morning. Replicate samples of the milled material were taken of each of the 5 different compositions tested and of the excess garbage for moisture content determination. The composition of the material sent to Purdue is given in Table 44.

TABLE 44

Schedule of Samples to be Tested, Series II

Weight dry garbage	20 lbs.	20	20	20	20
Weight wet garbage	54 lbs.	54	54	54	54
Total sample weight	320 lbs.	167	114	91	67
% Wet garbage (wet weight basis)	17	32	47	59	81
Amount to be fed per cage per day*	21.3 lbs.	11.1	7.6	6.1	4.5

*Assuming 60 grams of dry garbage per rat per day (double daily minimum requirements, assuming garbage is able to sustain life)

Immediately after milling, the various compositions of waste were placed in cardboard barrels lined with sealed plastic bags, covered, and transported to Purdue where they were refrigerated until use.

The procedure used for milling the various compositions is of special interest. Because of the large amount of work involved in mixing unprocessed refuse, only slightly more than those quantities necessary for the cage tests were made up. Piles of these various compositions were then placed on the feed conveyor of the Tollemache mill and ground and bagged separately, to keep them distinct, for shipment. One of the results of this procedure, as will be apparent later in this report, is that an abnormally coarse particle size of the milled material resulted.

Four levels of garbage content were tested at Purdue--the 17, 32, 47, and 59 percent. Two levels were run concurrently for at least 2 weeks. The tests were run outside, with the cages covered by canvas awnings. Five male and 5 female rats were used in each test. The animals were conditioned to the tanks for 3 days, during which they were fed the same rations as were being fed in the large holding pens. On the fourth day the animals were weighed and the appropriate amount of milled refuse introduced to begin the test. Water and refuse were changed and the rats weighed daily. The results of the weighings are summarized in Table 45.

TABLE 45

Results of Purdue Rat Tests, Series II

Garbage content (%)	17	32	47	59
No. of days of test period	15	15	18	18
Total wt. of males-initial (grams)	2279	2312	2035	2440
Total wt. of males-final (grams)	2091	2064	2083	2129
Total wt. loss of males (grams)	188	248	(-) 48	311
Total wt. of females-initial (grams)	1822	1880	1985	1926
Total wt. of females-final (grams)	1576	1619	1686	1602
Total wt. loss of females (grams)	246	261	299	324

No animals died as a result of starvation or cannibalism. There was some weight loss, but no significant trends are observable between weight loss and garbage content.

A likely reason for the apparently contradictory results of this test series in comparison with the previous one is some unexplainable mixing of small portions of unprocessed refuse with the milled refuse. Another possibility is that heavy wet food wastes were able to fall rapidly through the mill and leave the mill relatively unground. Paper and other materials normally tend to retard the rapid flow of refuse through the mill, giving a finer grind. Also, having allowed the mill to clear itself before feeding each pile promoted an unhindered fall of the initial portions of each refuse batch through the mill, and some of the batches were so small that steady grinding conditions were never reached. The coarse grind resulted in edible matter readily available to the rats (Figure 46).

The conclusion reached from this test series is that particle size is of special importance in determining the suitability of milled refuse for sustaining the life of rats.

Test Series III:

Test Series III was designed to correct the problems encountered in Series II and thus to determine the effect of various garbage contents in milled refuse on the ability of that refuse to support rat life. In order to avoid the effort involved in separating garbage from the residential-light commercial wastes collected in Madison, special arrangements were made to obtain garbage and garbage-free refuse from a restaurant and a nearby village, respectively. The restaurant is a high volume operation which normally uses large garbage grinders to dispose of food wastes in the sewerage system. Over a weekend, the busiest period of the week, the management agreed to place the wastes in barrels lined with several plastic bags. Approximately 300 lbs. of food scraps were collected, the bags tied securely, and stored at 4^{o} C. until needed a few days later. This waste was undoubtedly closer to being 100 percent food for rats than the handpicked garbage used in previous tests. No paper, plastic, metals, or glass was included. There was some concern over what seemed to be a large fraction of chicken bones, so the larger ones were removed and not used for subsequent testing.

The garbage-free refuse was obtained from the regular collection vehicles used in the village of Shorewood Hills, Wisconsin. This village has garbage grinders in all of the residences, and has no industry and virtually no commercial solid waste. The village president was very cooperative, and instructed the collection crew

Figure 46. Coursely Ground Refuse Used for Rat Tests at Purdue University

to avoid food wastes or garbage as much as possible during pickup. Thus large amounts of food wastes which would not normally be ground in a garbage grinder were avoided as much as possible by the action of the collection crews. Once this material was dumped on the floor at the mill, an estimated 3 to 5 percent of garbage matter was removed by hand to provide extra insurance that the refuse as mixed was of accurate composition.

The desired mixture of garbage and rubbish was mixed and placed on the feed conveyor to the Tollemache mill. Twice the required amount was milled. The first and last quarters of the milled product were not used for the tests. Preliminary testing indicated that, if the first and last quarters were 125 lbs. or more, beginning and end effects on the particle size would be most noticeable in these quarters, leaving a good grind in the center half of the milled material. As a further precaution, new hammers were installed in the mill shortly before it was used to prepare the refuse for testing at Purdue. Multiple samples were taken of the milled refuse product and garbage for moisture content determination. The milled material was placed in plastic-lined fiber drums which were sealed and transported to Purdue where they were held under refrigeration until use. The composition of the material used for testing is shown in Table 46. Note that only 50 percent excess garbage was provided per rat per day above the minimum average requirement. This reflects the much greater likelihood that the garbage in this test series was more nearly 100 percent utilizeable by rats than the garbage used in the previous cage tests.

TABLE 46

Samples Tested at Purdue, Series III

Weight dry garbage	14 lbs.	15 lbs.
Weight wet garbage	50 lbs.	50 lbs.
Total sample weight	500 lbs.	250 lbs.
Percent wet garbage (wet-weight basis)	10%	20%
Amount to be fed per cage per day*	35.7 lbs.	16.7 lbs.

*Based on 45 grams of dry garbage per rat per day, which is 50 percent more than the normal daily requirement.

The cage tests were run at Purdue following the same procedure used for Series II, except that the daily rations of milled refuse were reduced proportionately whenever an animal died.

The results were that all 10 animals died within the 15-day duration of the test with the 20 percent garbage material, whereas only 5 of the 10 animals died in the test using the 10 percent garbage material. The 20 percent test would seem to confirm Series I results that rats cannot survive on a diet of only milled refuse (except in the earlier test 15 percent garbage was assumed, while in this test 20 percent garbage was known to be present).

The results of the 10 percent garbage test indicate that this material is certainly not conducive to survival, with half of the original 10 rats dead after 15 days. However, the results are not as conclusive as would be expected since 5 rats did survive. Of the 5 survivors, 4 were very weak and would have died shortly had the test continued, while the fifth was a dominant male which seemed to thrive. Extensive discussions were held with Purdue personnel about this test in an attempt to understand its outcome. The following possibilities were noted:

1) The labels on the 10 and 20 percent samples were reversed. This is very unlikely, as 250 lbs. of 20 percent and 500 lbs. of 10 percent material were sent, and then weighed in correctly at Purdue.

2) The samples were initially mixed incorrectly. This also appears unlikely as twice as much of the 10 percent material was prepared (1,000 as opposed to 500 lbs.), yet an equal amount of garbage was used in each case (100 lbs.).

3) The 10 percent sample was not of uniform composition. Mixing prior to milling, plus the mixing effect of milling makes this unlikely, although it does remain a possibility.

4) A coarse particle size was obtained with the 10 percent sample. This does not seem to be the cause, since the grind appeared to be equally fine in each case and special attention was given to this matter as a result of the previous test series.

5) The make-up of the 10 rats selected for the 10 percent test led to the results. This appears to offer a plausible explanation of the results although it still seems unlikely. Rats were trapped and removed from the large outdoor pens

for testing. Those rats which were too small (less than 300 grams) or apparently not in good physical condition were not used in the tests. In practice, 3 times as many rats as needed for the test are generally trapped so the selection criteria are quite rigid. The goal is to get 10 similar and compatible rats, which is, of course, not always possible. One of the reasons for the acclimation period in the test cages prior to the actual test is to check for compatibility in a confined area.

It is possible in the 10 percent test that 5 relatively weak and 5 relatively strong rats were selected, and that one of the 5 stronger rats was the dominant male. Thus, by fighting off the weaker rats, the 5 stronger rats were able to get what food was available through cannibalism and in the milled refuse. This food, plus stored energy, enabled the stronger animals to survive. The dominant male was probably very good at this, and he survived quite well. If the test were continued, the weaker rats would have died and the dominant male would probably have continued to live for some time, surviving again by fighting other rats to cannibalize them or get available food. It is doubtful that he could have survived long solely on milled refuse.

It is interesting to note that in test Series II, the females, which had an average initial weight of 381 grams, lost 15 percent of their weight during the test period; whereas, the males weighed 453 grams on the average initially and lost 5.5 percent of their initial weight. This supports the statement that the larger, more dominant rats tend to thrive better, and lends weight to this explanation of the results of the 10 percent garbage test.

6) Maybe the 10 percent results are not the entire problem and the 20 percent results should also be examined more carefully. It is interesting to note that the results of Series I, with freshly milled refuse of approximately 15 percent garbage content, were that 3 and 2 rats remained at the end of the duplicate 15-day experiments. This is not that different from the 10 percent results and, in fact, the 20 percent results could have led to the apparent dissimilarities in the third test series. It is possible, for example, that 10 rats of relatively equal strength were selected in the 20 percent test so no rats could become so dominant as to win sufficient food to exist for the entire test period.

No matter what the reason for the survival of half the rats in the 10 percent tests, the results of this test series still lead to the conclusion that rats cannot survive indefinitely on a diet consisting only of milled refuse.

CONCLUSIONS

The conclusions resulting from the confined cage studies in which rats were fed only milled refuse, subject to the conditions of the experiment, are as follows:

1) Rats are not able to survive on milled refuse containing up to 20 percent wet garbage on a wet-weight basis. They become progressively weaker with time and resort to cannibalism to prolong survival.

2) The particle size of the milled refuse is of great importance. Rats did survive on poorly ground solid waste containing as little as 17 percent garbage, although there was close to a 12 percent average weight loss over the 15-day test period with this material.

3) All cage tests were conducted in an admittedly biased situation, which would make the results more positive than under actual field conditions. Normally rats will simply move to a more desirable location when faced with something they do not like, but in the cage tests there was no choice. Thus, in interpreting these tests, where the rats could not live on the material in a no-alternative situation, it should be noted that there is even less possibility for rat infestation and survival in a milled refuse landfill than apparent from the cage studies.

VI. PRODUCTS OF DECOMPOSITION-LEACHATE AND GAS

VI-A - Olin Avenue Field Studies

One of the goals of the City of Madison refuse milling project is to evaluate the use of milled refuse in a landfill situation. Of particular importance in this regard is the effect of milled refuse in a landfill on the environment, and the effect milling has on the rate of stabilization of refuse, if any. Two basic landfill constructions have been investigated: milled refuse compacted and left without cover and unprocessed refuse compacted and covered with earth. These were monitored to have a basis for comparing their effects on the surrounding environment. Indicators of the pollutional and decomposition effects are the amount and composition of the collected water and composition of the gas emanating from the refuse piles.

The leachate (water) analysis has shown that milled refuse decomposes faster than unprocessed refuse. The two basic parameters used to show this decomposition are chemical oxygen demand (COD) and specific conductance. Other leachate parameters included volume collected, pH, biological oxygen demand (BOD), hardness, alkalinity, chlorides, nitrogen, and phosphorus. Gas analysis indicating increased levels of methane gas showed that the refuse was decomposing; however, due to the effects of factors which could not be controlled, it is difficult to use gas results to compare the relative decomposition rates between the two cell constructions.

INTRODUCTION

This section presents the results of outdoor studies on the relative degradation characteristics of milled refuse without daily cover, compared with unprocessed refuse covered in the normal sanitary landfill manner. Degradation and the attendant pollutant production were evaluated by monitoring leachate and gas production. The reader is referred to the definitions at the beginning of the report where terms used routinely in this and following sections are defined.

General Cell Set-up:

To conduct this evaluation of the environmental effects of solid waste degradation, 22 test cells were constructed at Madison's Olin Avenue landfill site between October 1967 and August 1968, as shown in Figure 47. Unprocessed combined refuse (UCR) cells were constructed by placing the refuse in layers, compacting them with a D-7 Caterpillar tractor, and then covering them with at least 6 in. of earth to represent the typical sanitary landfill situation. The milled combined refuse (MCR) cells were placed and compacted in similar fashion, but were not covered.

In addition, four special cells were constructed only for experimental purposes to represent the extremes in landfill situations. Material for these cells was obtained from a separate garbage collection being operated at that time on the east side of Madison. Two of the cells were composed of garbage (food wastes) - one unprocessed (UG) with 6 in. of earth cover and the other milled (MG) without earth cover. The other two special cells were composed of rubbish - one unprocessed (UR) and the other milled (MR), with and without earth cover respectively.

All of the cells were approximately 5 to 6 ft. deep with lengths and widths ranging from 40 to 200 ft. No two cells were alike. Data on the cells of particular interest to this report are given in Table 47. (Note that some of the cells which were not instrumented for monitoring either gas or leachate are excluded from this list.)

Experimental Procedure

The environmental effects of solid waste degradation were evaluated through the study of physical, chemical, and microbiological changes which occurred in the various cells during decomposition. More specifically, tests were conducted on the leachate and gas produced by the cells.

Of special importance to any study of refuse decomposition is the composition of the refuse. During this study period, the federal government conducted several tests on the composition of Madison's solid waste, as indicated in Appendix N. The results suggest that the refuse is generally typical when compared with national figures or data available from other municipalities.

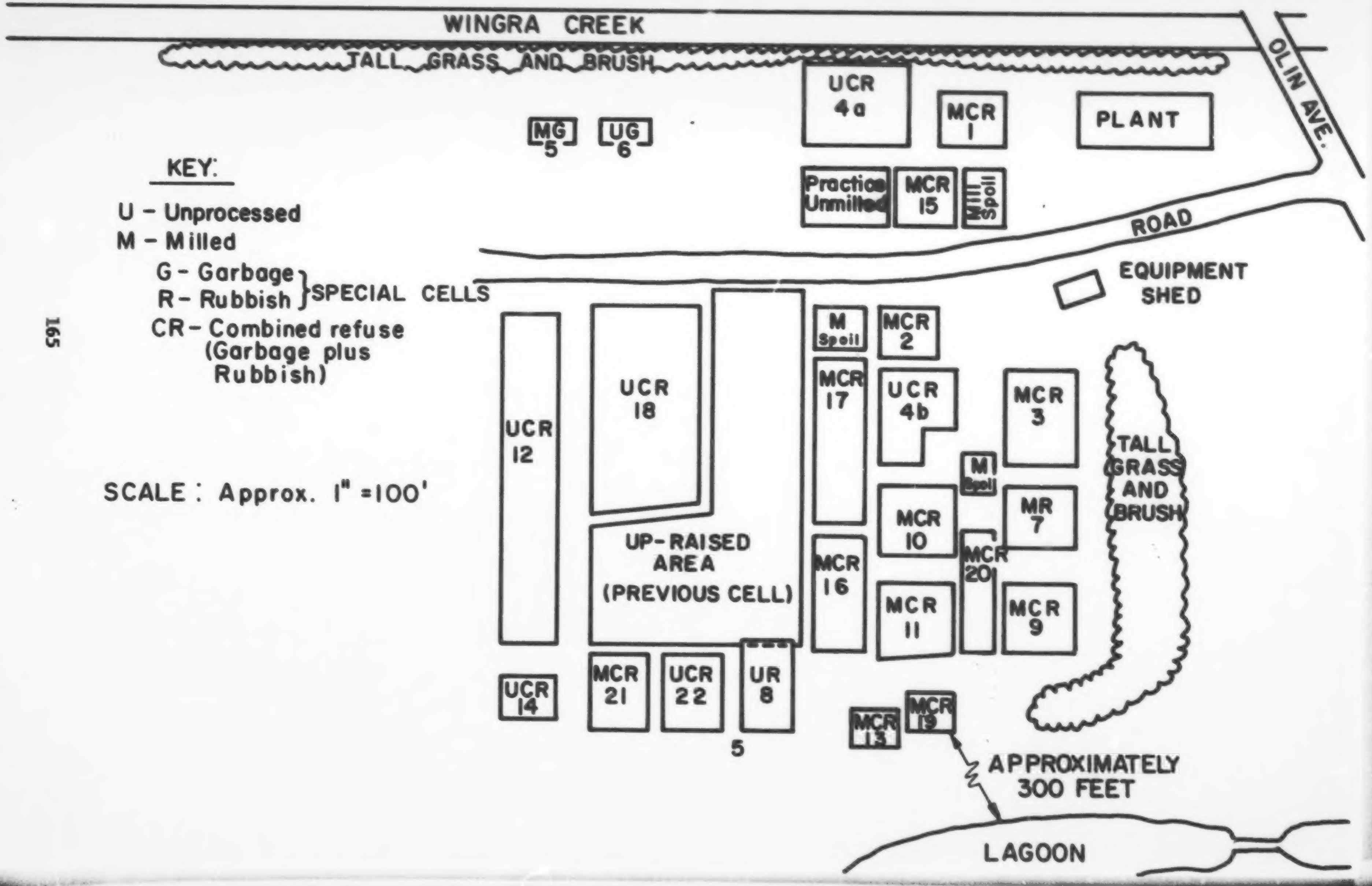
Leachate Sampling and Testing:

Reservoir Construction

In cells 2, 3, 4b, 5 through 14, 21 and 22, bell-mouth concrete pipes were placed vertically in holes dug beneath the cell bottoms, with the lower ends sealed with concrete to act as leachate collection reservoirs. Projecting up from the bell-mouth end of each pipe and through the refuse was a 6-in.-inside-diameter polyvinyl chloride pipe. Just above the bell-mouth, slits were made in the PVC pipe to allow passage of leachate into the concrete reservoir. Leachate was directed to the slits by use of a 40 x 40 ft. section of plastic sheeting sloped to the reservoir. The upper end of the PVC pipe was capped with galvanized metal to exclude precipitation from the reservoir and to minimize evaporation losses.

FIGURE 47

CELL LOCATIONS, OLIN AVENUE TEST SITE


WINGRA CREEK
TALL GRASS AND BRUSH
OLIN AVE.
ROAD
PLANT
UCR 4a
MCR 1
MG 5
UG 6
Practice Unmilled
MCR 15
Mill Spoil
EQUIPMENT SHED
M Spoil
MCR 2
MCR 17
UCR 4b
MCR 3
M Spoil
MCR 10
MR 7
MCR 20
MCR 16
MCR 11
MCR 9
TALL GRASS AND BRUSH
UCR 12
UCR 18
UP-RAISED AREA (PREVIOUS CELL)
UCR 14
MCR 21
UCR 22
UR 8
5
MCR 13
MCR 19
APPROXIMATELY 300 FEET
LAGOON

KEY:

U - Unprocessed
M - Milled
G - Garbage } SPECIAL CELLS
R - Rubbish } SPECIAL CELLS
CR - Combined refuse (Garbage plus Rubbish)

SCALE: Approx. 1" =100'

TABLE 47

Summary of Test Cells - Olin Avenue Site

Cell No. And Type	Type of Waste Composition	Tons	Grate Size Used in Milling	Period of Construction
MILLED CELLS				
1	Refuse	534	3 1/2	Sept. 18 - Oct. 6, 1967
2	Refuse	450	2	Oct. 9 - 27, 1967
3	Refuse	703	6 1/4	Oct. 30 - Nov. 17, 1967
9	Refuse	474	6 1/4	Dec. 11 - 29, 1967
10	Refuse	689	3 1/2	Jan. 2 - Feb. 1, 1968
11	Refuse	844	6 1/4	Feb. 2 - March 18, 1968
13	Refuse	319	3 1/2	March 18 - 29, 1968
15	Refuse	617	3 1/2	April 1 - 19, 1968
16	Refuse	739	6 1/4	April 22 - May 13, 1968
17	Refuse	733	5	May 13 - 31 ,1968
19	Refuse	499	5	June 3 - 14, 1968
20	Refuse	430	4	July 8 - 20, 1968
21	Refuse	709	6 1/4	July 29 - Aug. 20, 1968
23	Refuse	420	5	Oct. 10 - 22, 1968
5	Garbage	103	6 1/4	Nov. 20 - Dec. 1, 1967
7	Rubbish	310	6 1/4	Nov. 27 - Dec. 8, 1967
UNPROCESSED CELLS				
4A	Refuse	1045		Sept. 18 - Oct. 18, 1967
4B	Refuse	683		Oct. 23 - Nov. 17, 1967
12	Refuse	1456		Jan. 8 - March 15, 1968
14	Refuse	197		March 18 - 29, 1968
18	Refuse	1268		April 1 - May 31, 1968
22	Refuse	548		July 29 - Aug. 20, 1968
6	Garbage	38		Dec. 4 - 8, 1967
8	Rubbish	400		Feb. 12 - March 5, 1968

Field Sampling

To obtain a leachate sample, the following procedure was used. The galvanized metal cover was removed and rubber tubing of sufficient length was dropped into the reservoir. Connected to the rubber tubing were a 2-liter sampling flask, a trap flask, and a vacuum pump, in that order. Electricity to run the pump was supplied by a portable gas generator. The trap flask was used to prevent leachate from accidentally getting to the vacuum pump and causing damage.

Data obtained in the field included the amount of leachate pumped (in milliliters) and the temperature of the leachate (in degrees centigrade). Temperature was obtained by securing a thermometer to a lath, lowering it into the leachate, and then pulling it out quickly for recording.

In obtaining a sample, the first 2,000 milliliters were discarded. The sample was obtained from the second 2,000 milliliters to make sure that any leachate from previous samplings would be rinsed out of the flask.

Laboratory Analysis

Previous experience with leachate analysis has indicated that results will vary due to interferences being present which depend on the amount of suspended matter in the sample. Furthermore, the amount of suspended matter is a function of many uncontrollable factors not necessarily related to the decomposition process. This problem was overcome by using a decanting technique. When a sample was brought in, it was shaken and then left to settle. After 4 hours the supernatant was decanted off. All samples were treated in the same way. Data show that the samples after decanting were low and uniform in suspended solids. This procedure is felt to correspond to actual landfill conditions where most suspended matter will be filtered from the leachate by passing through a few inches of soil.

Leachate commonly contains a wide variety of compounds or contaminants, frequently in very large concentrations. Rather than attempt to obtain the concentrations of each of the many species that might be present, it was decided to categorize the more important ones and use gross analyses to determine their presence as a group wherever possible. In addition, certain species were analyzed because of their individual importance, or because they represent a group of similar species which are of interest.

The following analyses were conducted on the leachate samples obtained:

CHEMICAL OXYGEN DEMAND: The chemical oxygen demand (COD) is a widely used evaluation of the amount of oxygen needed to oxidize chemically the matter in a water sample. As used for these studies, the test results may be considered primarily related to the amount of organic matter although, in anaerobic waters with high concentrations of oxidizable cations, inorganics can add to the COD as well. The test was run according to the procedure delineated in the 12th edition of Standard Methods. Because of the very high levels of COD in the leachate samples, dilution with distilled water was sometimes required prior to analysis.

CONDUCTIVITY: Like the COD test, conductivity, or more correctly specific conductance, is a gross indicator of the total concentration of a major classification of contaminants in water. The test results may be considered a measure of the concentration of dissolved inorganic matter, or ions, and is commonly related to the total dissolved solids (TDS). Conductivity plus COD give a good indication of the organic and inorganic content, respectively, of a water sample reasonably free of particulate matter. This test was run using a conductivity bridge, Model RC16B2, made by Industrial Instruments.

pH: pH is a measure of the hydrogen ion concentration and it was found to be an indicator of the state of refuse decomposition. Values were obtained using a Beckman Zeromatic II, Model 96A, pH meter.

ALKALINITY: Alkalinity was measured by titration to pH 4.3 using a pH meter.

TOTAL AND CALCIUM HARDNESS: Hach kits which incorporate a micro version of the EDTA titration method for hardness were used to determine total and calcium hardness. Kits HA-71 and HA4P were used following the directions supplied with the kits. The Standard Methods EDTA titration procedure was used during the last project year and as a periodic check on the Hach kit results. Comparison between the two methods was close enough to allow continued use of the Hach kits.

CHLORIDES: Chlorides were tested initially using a Hach kit, Model 7-P. Only samples collected after March 1969 were run. It should be noted that in the latter part of the project, a full-time chemist was employed to conduct the above tests. During this time the Argentometric method outlined in Standard Methods was used, where interferences from orthophosphate and iron were handled by special reagents as outlined in the procedure. There were no major changes in magnitudes when the Standard Method's procedure was substituted for the Hach kit, indicating the relative reliability of the Hach kit results.

NITROGEN AND PHOSPHORUS: Total nitrogen was determined using the Kjeldahl procedure. Total, ortho-, and soluble phosphates were determined using the stannous chloride method. Both procedures are outlined in Standard Methods.

BIOCHEMICAL OXYGEN DEMAND: BOD tests were run during the early part of the study according to procedures outlined in Standard Methods. However, because of high dilutions required (usually greater than 1/20,000) the results were not very reproducible. Because of this difficulty, seeding problems, and other reasons, the BOD test was abandoned and not used as an indicator of organic material concentrations.

Gas Sampling and Testing:

Gas Probe Construction

Gas sampling probes were installed in cells 1, 2, 3, 7, 8, 10, 11, 12, 14, 16, 18, 21 and 22 at depths of 1, 3, and 5 ft. from the surface using a post hole digger. The probes were constructed of 1/4 in. I.D. rubber hose, plastic funnels with 4 in. diameter tips, and galvanized screen. Each funnel was inserted in rubber tubing and secured by wrapping wire around the connection. Galvanized screen was bent around the open funnel to prevent it from being clogged with refuse.

This assembly was inserted in the holes and the refuse replaced and packed down. The projecting end of the rubber tubing was stoppered with a rubber cork to prevent contamination of the gas in the tube by the atmosphere.

Sampling Procedure

Gas samples were collected using 100-ml gas collecting flasks, a trap flask, vacuum pump and a portable generator. Using a vacuum of 5 psi, the pump was run for 30 sec. to insure that the gas flasks were evacuated and that gas from within the cell was being collected. Special tests led to this as the best sampling procedure.

Laboratory Analysis

Gas analyses were conducted using a Fisher gas partitioner, Model 25V, with helium as the carrier gas and a gas flow rate of 80 ml/min.

Results and Discussion

Theoretical Basis for Discussion:

A simple water budget at the surface of a refuse cell indicates that incident precipitation can leave the surface as runoff, be directly evapotranspired to the atmosphere, or infiltrate downward into the cell. Water which infiltrates will increase the moisture content of the surface layer until that layer can hold no more moisture, whereupon the addition of more water will saturate the next lower layer, etc. As the process continues, more and more of the cover soil or refuse becomes saturated until the entire cell mass can hold no more water. At this point, more infiltrate will theoretically add more water than the refuse and soil can hold, and a like amount of water will be displaced from the cell. This water is defined as leachate, as discussed in an earlier section of this report. Refuse or soil which can hold no more water is said to be at field capacity.

It is apparent that the amount of leachate generated once field capacity has been reached as well as the precipitation necessary to reach field capacity are both functions of the water budget at the top surface of a refuse cell. If the cell is covered with anything but properly sloped, impermeable clays and fine silts, there is some infiltration in humid climates. (This must be so, otherwise many parts of the county would have little or no ground water replenishment.) With milled refuse in the absence of cover, it may logically be predicted that there will be little runoff, but increased amounts of evaporation when compared with reasonably fine soils as fine sands, loams, silts, etc.

The goals of this study include the determination of whether leachate is produced under Madison's climatic conditions and use of cover soils. This was to be done both for unprocessed compacted refuse covered with compacted soil, as in a sanitary landfill, and for milled compacted refuse without cover. The cover soil to be used, when required, was the same as that used locally at sanitary landfills. In addition, leachate quality was to be evaluated to assess the danger this material presents to ground and surface waters, and to better understand the decomposition taking place in the two basic cell constructions.

Leachate:

First it must be stated that leachate was indeed produced by both unprocessed and milled cells. However, direct comparisons of leachate data from the various cells is difficult because the cells differed from one another in size and shape. Indeed, even within a given cell the leachate produced represents only that collected by the tarp and not the total production of the cell. This is because the tarp underlies only part of each cell. Thus, different amounts of leachate were collected from cell to cell, and the actual amount collected from each cell may not be representative of that cell's entire production. Because of this, a determination of the water budget, or a presentation of data in terms of volumes of leachate produced per volume or weight of refuse, cannot be made. For these reasons, only the general shapes of the leachate volume and related curves will be considered. Note that exceptions to this rule exist only when considering concentrations, where the leachate collected may be assumed to be comparable to that generated over the entire cell.

One problem observed in considering only the COD concentration of leachate is that, on occasion, samples containing high COD concentrations were collected at times when very little leachate was produced. Throughout the study, therefore, COD values in terms of grams of COD produced per sampling period were obtained by multiplying the COD concentration by the volume of leachate produced. Curves of grams of COD produced provide a more realistic display of the effect of the cells on the environment because they indicate the total amount of matter which must be degraded to a non-oxygen-demanding state. Because only a portion of the leachate volume produced was collected for study, these curves are only indications of the total grams of COD produced in each cell. Thus, the shapes of the curves are useful, although the actual numbers should not be compared. It should be noted that multiplying the two parameters together tends to dampen extreme fluctuations in either leachate volume or COD concentration.

Curves of conductivity are shown to indicate the concentration of dissolved inorganic matter present in leachate at different stages of refuse decomposition. It was found that generally the conductivity and COD curves were similarly shaped, although notable differences occurred with refuse cells of different compositions.

Other tests run included alkalinity, calcium and total hardness. Graphs of these curves are not shown here, for it was noted that they follow closely the shape of the conductivity curves which are, after all, gross indicators of the sum of the concentrations of these and all other ions. The reader is referred to Table 48 which shows minimum, maximum, and

TABLE 48

Maximum, Minimum, and Average Values of Various Specific Ions

Cell No.	Cell Type	Maximum		Minimum		Average	Tendency[1]
TOTAL HARDNESS - MG/L @$CaCO_3$							
2	MCR	9138	7/9/68	600	7/8/71	2317	-
3	MCR	9988	6/27/68	430	4/5/71	1647	-
5	MG	11050	3/1/69	400	8/10/71	3135	-
6	UG	6250	4/8/69	925	11/2/71	3317	-
7	MR	710	3/1/70	162	10/23/69	376	+
8	UR	1830	8/4/69	820	8/3/70	1181	-
12	UCR	4940	8/4/69	1198	3/6/70	2553	+
14	UCR	6660	10/23/69	680	10/19/68	3081	+
CALCIUM HARDNESS - MG/L @$CaCO_3$[2]							
2	MCR	3420	5/12/70	239	1/26/70	857	0
3	MCR	2295	7/11/69	203	1/26/70	616	0
5	MG	5950	7/11/69	256	4/3/70	974	-
6	UG	2560	5/12/70	137	12/4/69	1040	0
7	MR	580	3/1/71	102	10/23/69	332	+
8	UR	894	8/4/69	342	4/3/70	543	0
12	UCR	3060	8/4/69	427	3/6/70	1765	0
14	UCR	3760	10/23/69	1530	7/11/69	2630	0
ALKALINITY - MG/L @$CaCO_3$							
2	MCR	8200	7/9/68	705	7/8/71	2544	-
3	MCR	6900	6/27/68	207	3/6/70	1388	-
5	MG	16100	6/27/68	336	8/3/70	4795	-
6	UG	14800	10/19/68	1926	11/2/71	9686	-
7	MR	797	4/5/71	68	10/23/69	461	+
8	UR	1765	6/13/69	496	4/3/70	1064	-
12	UCR	6580	10/23/69	579	3/6/70	2601	+
14	UCR	10105	10/23/69	1310	4/8/69	3511	+

[1] + Implies that the curve slopes generally upward; 0 implies no tendency to rise or fall; - implies that the curve slopes generally downward.

[2] Tests of Calcium hardness begun on 7/11/69.

TABLE 48(Cont'd.)

Cell No.	Cell Type	Maximum		Minimum		Average	Tendency
CHLORIDES - MG/L @Cl[3]							
2	MCR	970	6/8/70	118	11/2/71	475	-
3	MCR	545	10/23/69	2	3/1/71	116	-
5	MG	3636	3/1/69	35	9/6/71	626	-
6	UG	3030	12/16/70	818	3/1/71	1638	0
7	MR	61	7/6/70	700	10/28/70	16	-
8	UR	462	6/13/69	106	10/28/70	276	-
12	UCR	879	8/4/69	152	3/6/70	513	0
14	UCR	2000	5/12/70	303	7/11/69	948	0
TOTAL IRON - MG/L @Fe[4]							
2	MCR	950	5/12/70	1.2	1/6/72	152	-
3	MCR	143	7/6/70	9.1	11/30/71	42	-
5	MG	103	2/2/71	2.6	8/9/71	17	-
6	UG	318	7/6/70	15	8/9/71	111	-
7	MR	91	6/8/70	2.2	10/5/71	28	-
8	UR	283	9/29/70	43	12/16/70	210	*
12	UCR	173	5/12/70	120	4/3/70	*	*
14	UCR	-	-	-	-	*	*
TOTAL NITROGEN							
2	MCR	304	8/3/70	13	1/6/72	115	-
3	MCR	353	1/28/69	5	5/5/71	70	-
5	MG	4200	7/30/68	0.7	11/30/71	922	-
6	UG	4000	10/19/68	44	1/6/72	1732	-
7	MR	201	7/6/70	1.6	11/30/71	45	-
8	UR	134	4/8/69	20	3/6/70	64	-
12	UCR	800	10/19/68	49	3/6/70	374	-
14	UCR	625	9/4/68	263	12/4/69	430	-
TOTAL PHOSPHATE [5]							
2	MCR	18.9	1/27/70	0.2	11/30/71	13	-
3	MCR	18.3	7/6/70	1.8	4/6/71	7.4	-
5	MG	99	2/2/71	1.0	11/30/71	34	-
6	UG	122	8/21/70	14	7/8/71	55	-
7	MR	24	6/8/70	0.2	11/30/71	5.8	-
8	UR	4.9	6/8/70	2.6	12/16/70	2.6	-
12	UCR	11	3/6/70	6.2	5/12/70	*	*
14	UCR	-	-	-	-	*	*

[3] Tests of Chloride begun on 3/1/69.

[4] Tests begun on 1/27/70. Data for Cell 12 for 6 months only, for Cell 8 for 1970 only, and no data available for Cell 14.

[5] Tests run prior to 1970 not considered.

average values for these and other tests. Minimum, maximum, and average values are also given for total phosphorus and nitrogen to give the reader a feeling for their magnitudes.

The final test was pH, the results of which revealed generally an inverse relation between the pH and the COD concentration curves. pH curves are shown for the combined refuse cells to illustrate the relationship with the COD curves.

To aid the reader in interpreting the graphs and figures, the following code will be used. A blank space indicates that there could have been a point at some level within the gap but none was obtained due to human error or equipment malfunction. The dashed line normally indicates an actual sampling attempt, but no sample was obtained (e.g., no leachate present).

Unprocessed Combined Refuse Cells

Cell Histories

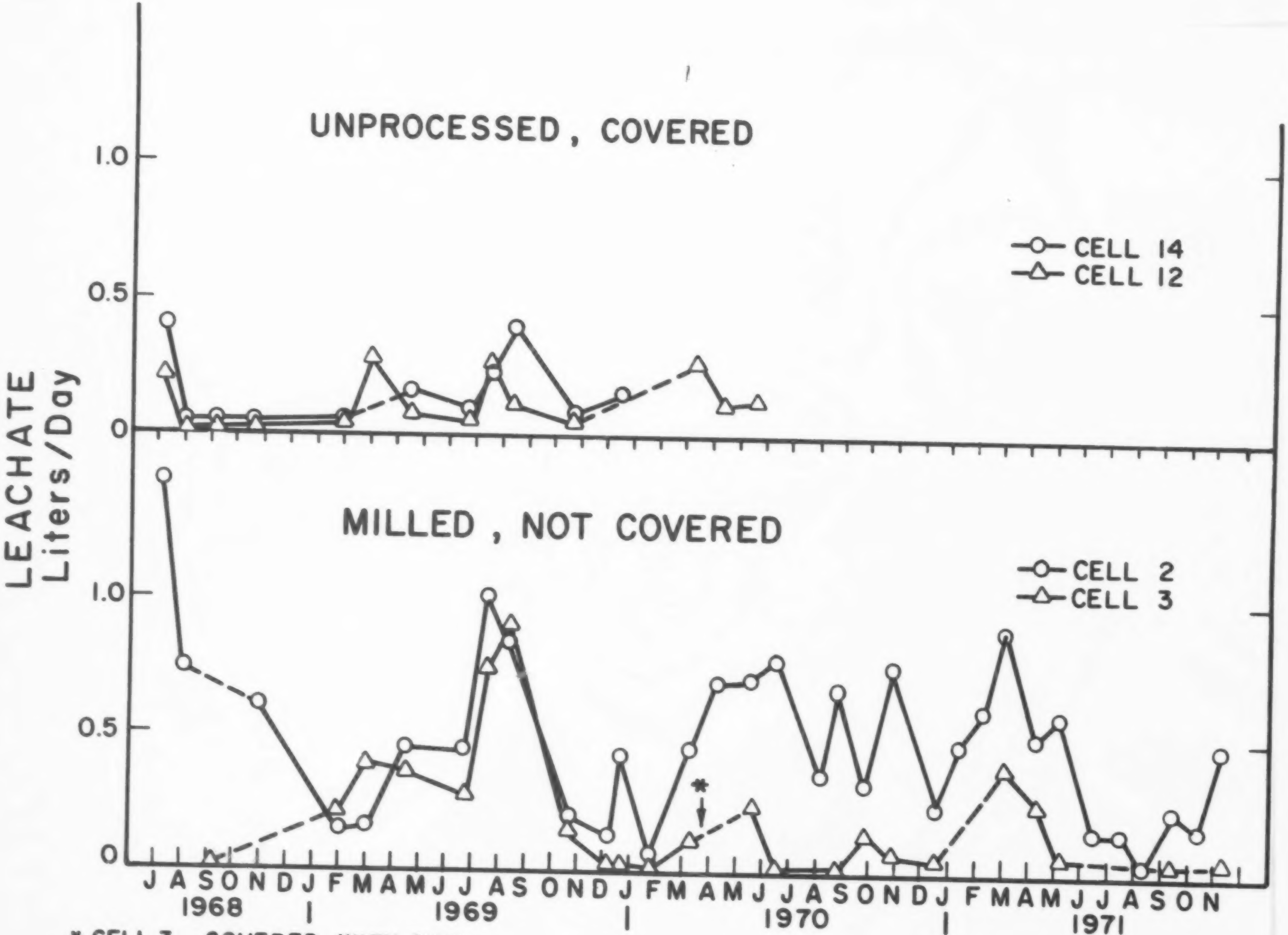
Cells 4b, 12, 14 and 22 were constructed of unprocessed combined refuse and covered with 6 in. of soil to represent the normal sanitary landfill situation. Problems were encountered with leachate volumes in cell 4b; at no time during the test period was it possible to pump dry the leachate reservoirs. It is surmised that groundwater flowed into the collection system by some means, producing a virtually inexhaustible supply of "leachate" which had very low COD concentrations in comparison with the other cells. Cell 22 produced collectible leachate only after periods of heavy rainfall; this suggested a leak in the collection system, allowing most of the leachate to escape. For these reasons, no meaningful conclusions could be drawn from these two cells.

Cells 12 and 14 seemed to operate satisfactorily until the entire landfill was brought up to final grade in winter and spring of 1970. The cells were completely covered with other materials, precluding any further study of them. Cell 14 was affected in the winter of 1969-70 and cell 12 in spring of 1970. At this time both cells started producing abnormally large amounts of leachate. The amounts were so large that it was impossible to pump the reserviors dry, suggesting a general rise of the water table in the area. All results from this point on were dropped from further consideration.

Leachate Production

Leachate production in liters per day is plotted on a time scale for cells 12 and 14 in Figure 48. These curves show a slight but steady increase in leachate volume from the onset of production, with seasonal and monthly fluctuations superimposed on the curves.

During the winter of 1969-70, no leachate was produced in either cell. This is indicated by the dashed line on the curve for cell 12. (Note that this is not shown on the curve for cell 14 since data for that cell were not good from the winter of 1969-70 on and therefore was not plotted.) This lack of leachate was probably caused by an early frost with little snow cover until the month of January, along with a general decrease in temperature within the cells due to decreasing biological activity which



* CELL 3 COVERED WITH DIRT.

Figure 48. Leachate Production, Combined Refuse Cells

allowed the cells to freeze. This same phenomenon was experienced on several of the other cells, as can be seen by their respective graphs.

COD Concentration

The most prominent feature of the concentration curves for COD for the unprocessed combined refuse cells, Figure 49, is the cyclic rise and fall of the COD with time. Closer examination shows that the peaks and valleys of the curve seem to be affected by seasonal temperatures, where peaks occur in the summer months and valleys in winter.

Another characteristic of the unprocessed cells is the lack of attenutation of the COD concentrations over the period studied. With cell 12 the COD concentration maintained a fairly constant level; whereas, with cell 14, the COD values rose somewhat and then exhibited a slight downward trend. This seems to imply that, with the unprocessed cells, the COD as expressed by concentration is released over a relatively long period of time when compared with, for example, the milled refuse degradation results.

COD Production

Over the period studies cells 12 and 14 both showed a gradual rise in grams of COD produced per day (Figure 50). The gradual release of COD as mentioned above is more readily seen in this plot than in Figure . Note the relatively high initial production of COD grams/day as compared to the rest of the curve. This suggests that some readily leached organics were present in the unprocessed combined refuse cells.

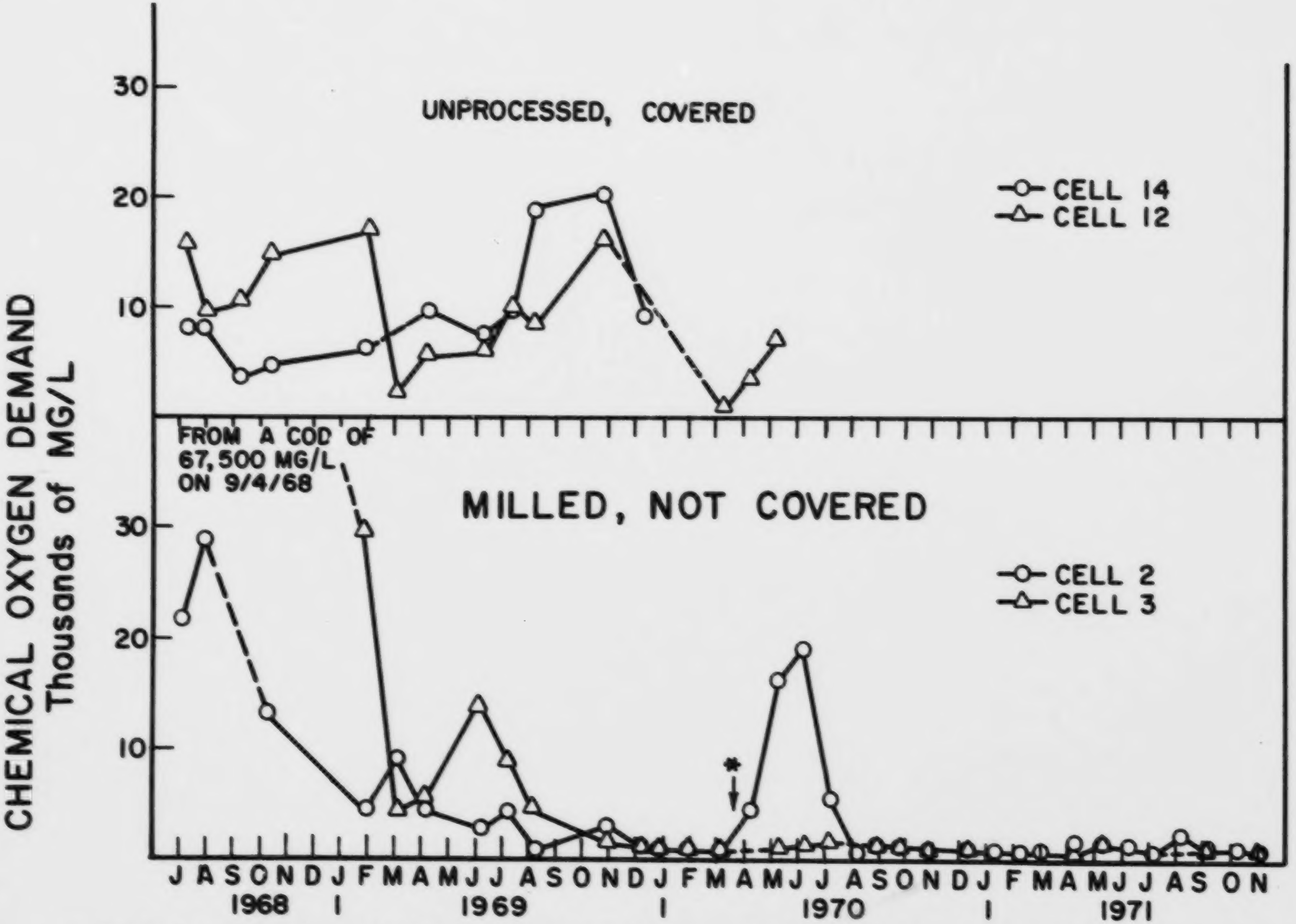
Conductivity and Other Specific Ions

With the unprocessed covered cells, the shapes of the conductivity curves bear a resemblance to that of the COD concentration curves (Figure 51). The seasonal rises and falls, for example, occur at approximately the same times. Also, a shape similar to the COD concentration curve is observed, indicating that the inorganic compounds which comprise the conductivity measurement are being released gradually over the test period. Alkalinity, chloride, and total and calcium hardness curves were of the same shape as the conductivity curve and so are not shown here. Maximum, minimum, and average values are given for these and other parameters in Table 48. Correlation coefficients were also determined and are given in Table 49.

Milled Combined Refuse Cells

Cell Histories

Cells 2, 3, 9, 10, 11, 13, and 21 were constructed of milled refuse and placed without cover during the 1967-68 period. Of these, cells 9, 10, 11, 13, and 21 were destroyed or rendered useless due to factors beyond the control of project personnel. With cells 9 and 10, sod and soil were put



* CELL 2 RECEIVED A LARGE DOSE OF WATER WHEN A NEARBY FIRE WAS BEING EXTINGUISHED

Figure 49. Leachate Chemical Oxygen Demand (COD), Combined Refuse Cells

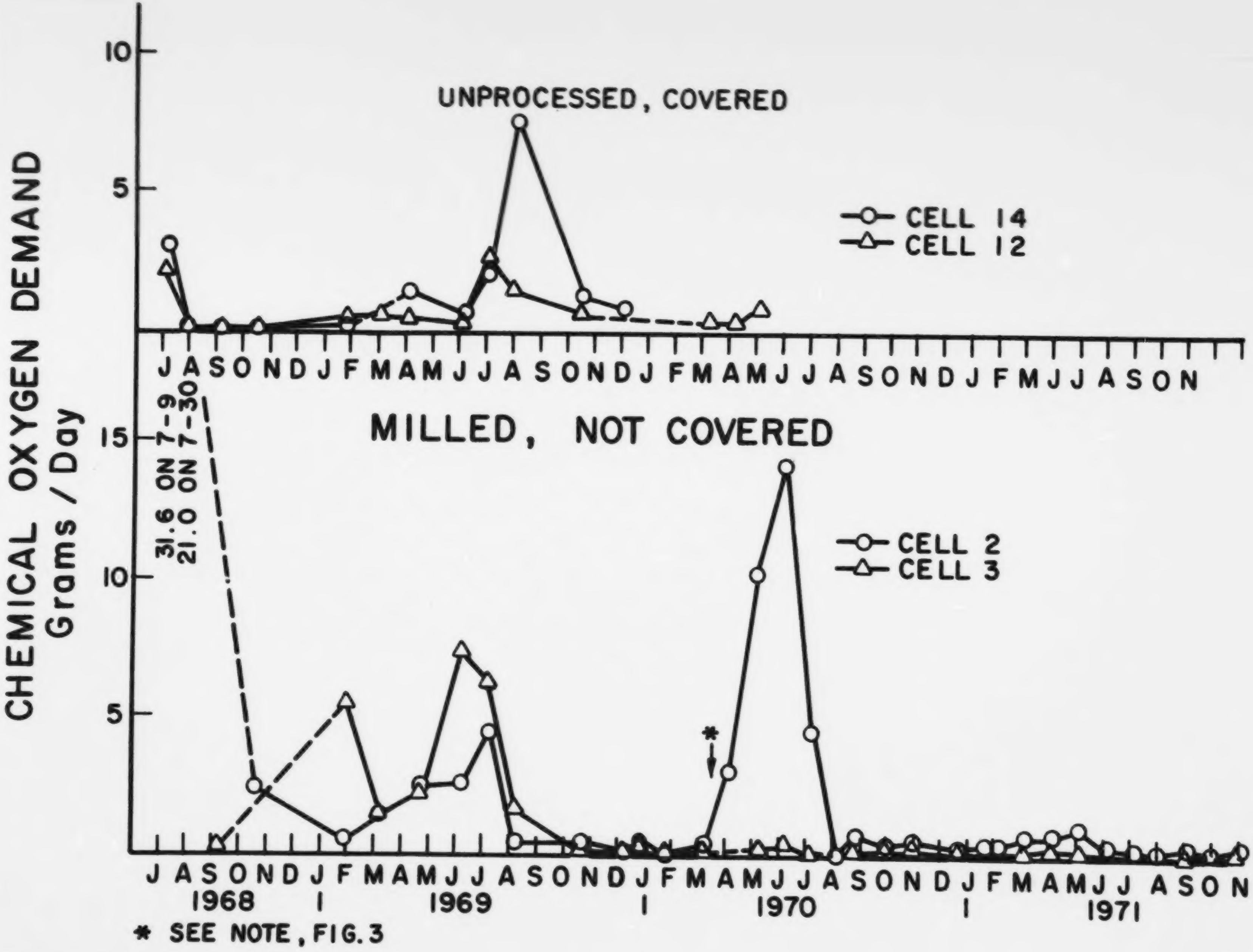


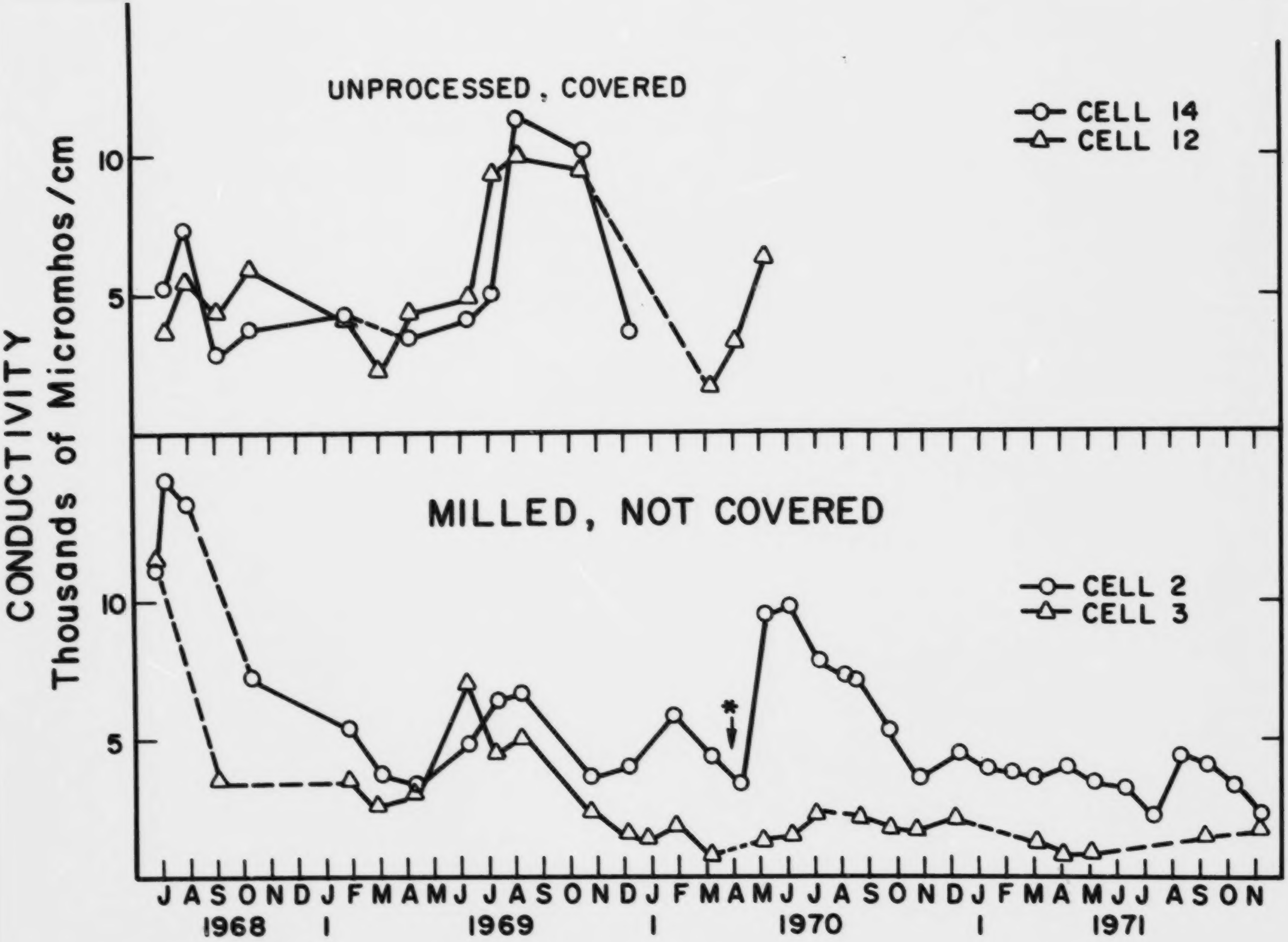
Figure 50. Leachate Grams of COD per day, Combined Refuse Cells

TABLE 49

Correlation Coefficient For The Following Parameters Vs. Conductivity

Cell No.	Cell Type	Total Hardness	Calcium Hardness	Alkalinity	Chloride
2	MCR	.88	.73	.92	.77
3	MCR	.98	.91	.98	.65
5	MG	.93	.99	.96	.92
6	UG	.45	.39	.74	.65
7	MR	.44	.25	.62	.35
8	UR	.74	.85	.87	.80
12	UCR	.88	.93	.98	.95
14	UCR	.77	.75	.68	.97

NOTE: 1.0 means perfect correlation (i.e., variable varies linearly with conductivity); greater than 0.5 generally accepted as some correlation, less than 0.5 little correlation, 0.0 means no correlation at all.



* SEE NOTE, FIG. 3

Figure 51. Leachate Conductivity, Combined Refuse Cells

on the cells a year after construction, resulting in the leachate collection systems being clogged with refuse dislodged by the heavy equipment. Cell 13 was destroyed entirely by landfill operations which encroached upon and finally covered the cell.

For approximately one year cell 11 gave a constant volume of leachate, after which it began producing more variable volumes. This suggests that a leak in the collection-reservoir system did not allow leachate to accumulate beyond a certain level; thus the cell seemed to yield a constant volume of leachate. Somehow the leak became plugged, perhaps by sediment, after which varying volumes of leachate were produced. In any case this made cell 11 results somewhat less than satisfactory. Cell 21 was destroyed in April 1970 while a fire which accidentally started in weeds on the cell was being extinguished.

This left cells 2 and 3 for analysis. Approximately 3 years after construction cell 3 was covered with 6 in. of soil; cell 2, however, has remained virtually untouched for the entire test period. The only unusual circumstance involving cell 2 occurred in April 1970. At that time it was doused with water while the fire which started on cell 21 was being extinguished. The fire briefly spread to cell 2.

Leachate Production

Production of leachate from cell 3 was intermittent and very slow at first, as shown in Figure 48. However, once the cell reached field capacity, leachate was produced consistently until April 1970, when soil cover was placed on the cell. After that leachate production was again intermittent and low in quantity. The apparent slowdown of production in cell 3 was probably caused by damage to the leachate collection system rather than to the soil cover itself, although some reduction in leachate production would naturally occur until the soil cover reached field capacity. The extent and timing of this decrease would depend on the runoff characteristics of the soil. Recorded field observations indicate that after the cover was placed, trouble was encountered in sampling due to debris in the sampling reservoir.

Cell 2, which has been left without cover throughout the sampling period, maintained a fairly constant rate of leachate production. It is interesting to note that the curves for cells 2 and 3 follow each other quite closely during the 1969 sampling year, indicating that after field capacity had been reached, the two cells reacted similarly. The two curves diverge after cell 3 was covered, with cell 2 continuing to produce approximately the same amount of leachate.

As mentioned before cell 2 was doused with water during a firefighting operation in spring 1970. This shows up as part, if not all, of the continued high level of leachate production from April until June 1970. The production curve then begins to drop back to what appears to be its normal level.

COD Centration

The COD concentration curves for the milled refuse cells are shown in Figure 49. The most prominent features of these curves are the relatively high initial COD values followed by a rapid reduction in concentration to relatively constant and very low COD values of approximately 500 mg./l. A small rise in COD does occur in cells 2 and 3 in the spring and summer following onset of leachate production, but this is relatively insignificant when compared with the general shape of the curve.

With cell 2 one immediately notices the sharp peak in the curve during summer 1970 for reasons mentioned above. The relatively high rate of water movement seemed to rinse more organics out of the cell than in the normal case, resulting in higher COD values. Two observations may be made as a result of this occurrance: 1) removal of organics from landfills could possibly be accelerated by intermittent dousing with water and; 2) the cell returned to normal conditions after the flood wave passed, as can be seen by comparing COD and volume curves of both cells 2 and 3 before and after the occurrence.

COD Production

The curves indicating the grams of COD produced in the milled cells, Figure 50, bear out the general characteristics of the COD concentration curve in that there is a steady decline in the COD produced over the period studied. The high initial COD concentrations from the milled cells are seen to be relatively unimportant when one considers the grams-of-COD curve. This is primarily because the initial volumes of leachate produced were relatively low even though the COD concentrations were very high. It is noted, though, that more grams are produced early in each cell's history.

Again with cell 2, the firefighting operation caused a sharp increase in the curve. However, the important consideration is that the curve returned to normal conditions shortly thereafter.

Conductivity and Other Specific Ions

As with the unprocessed cells, conductivity has the general tendency to follow the COD concentration curve but without dropping to the low levels observed with COD. The conductivity data are presented in Figure 51. With the milled refuse cells, this resulted in higher initial values followed by a general decrease in magnitude to fairly constant and relatively low values. Again there is the noticeable peak in the summer of 1970 on cell 2.

Alkalinity and the other specified ions follow the shape of the COD concentration curve closely. Typical values for these parameters, along with iron, phosphorus and nitrogen, are given in Table 48. Correlation coefficients relating various parameters with conductivity are given in Table 49. As has been mentioned previously and as shown on Figure 52, the general shape of the pH curve was found to compare quite well in an inverse relationship with the COD and conductivity curves.

Special Garbage Cells

Cell Histories

As mentioned previously, two test cells were constructed using specially collected garbage (food wastes) and packaging along with other wastes

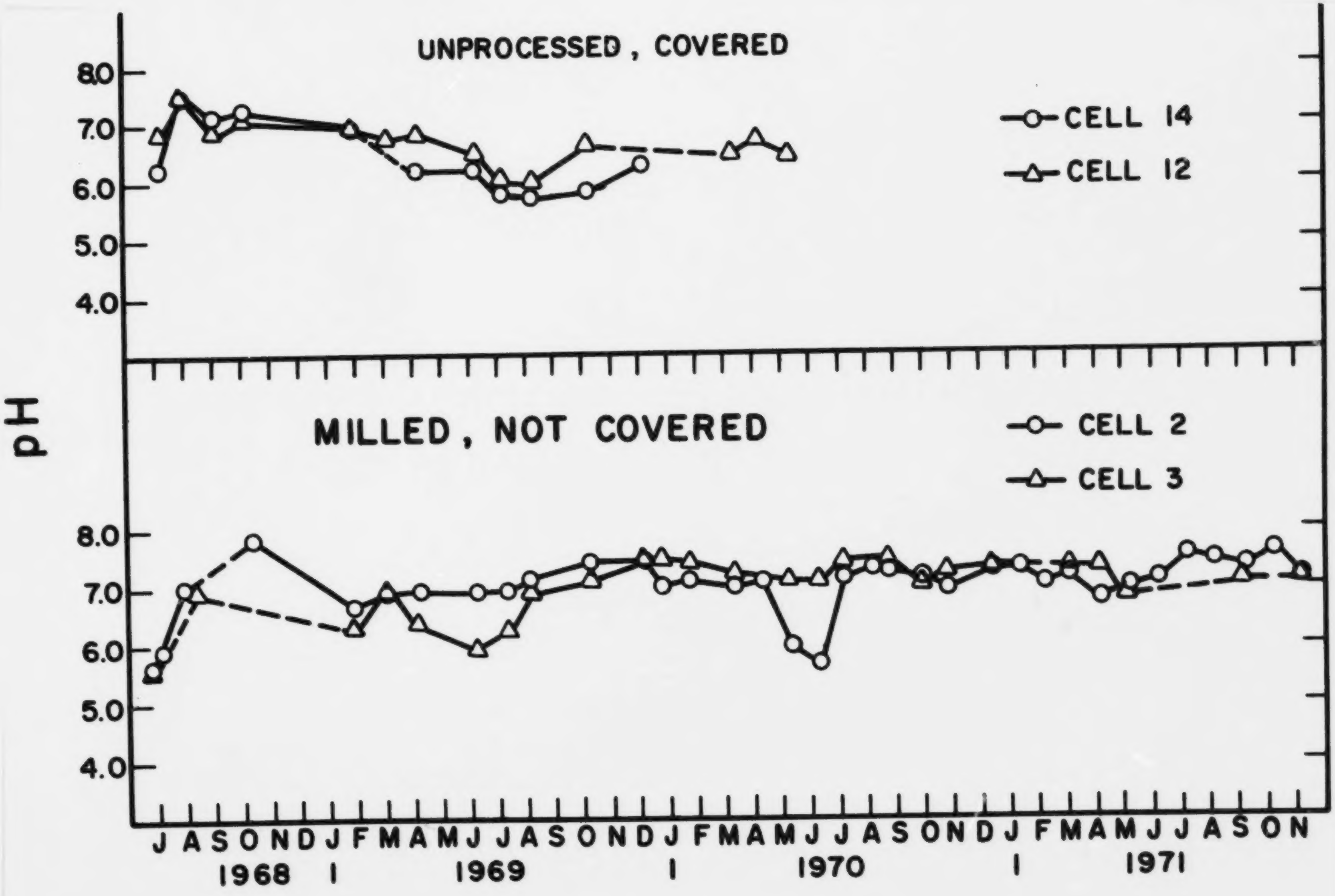


Figure 52. Leachate pH, Combined Refuse Cells

normally associated with garbage. Cell 6 was constructed of unprocessed garbage and covered with 6 in. of earth. Cell 5 was constructed of milled garbage. Early in the study, leachate began to seep out the sides of cell 5 and rodent problems arose. At this time the sides of the cell were covered with earth; the top, however, was left uncovered. It was hoped that these cells would yield data on the effect of milling the garbage fraction of solid waste with respect to degradation characteristics and landfilling properties.

Leachate Production - Unprocessed Garbage

Cell 6, the unprocessed garbage cell, began producing leachate in relatively large and more consistent quantities than did the unprocessed combined refuse cells. Figure 53 gives the results for cell 6. A higher initial moisture content and lack of a significant paper fraction to retard the downward flow of water by absorption in cell 6 probably accounts for this difference. For some unknown reason leachate production dropped off approximately 1 year after this initial period and continued at a relatively low level until it rose during the winter of 1971 to reach its former level.

COD Concentration - Unprocessed Garbage

Curves presenting the COD concentration for the special cells are found in Figure 54. The unprocessed garbage cell produced more concentrated leachate with respect to COD than did the unprocessed combined refuse cells. The curve exhibited increases in the summer and decreases in the winter and generally declined over the test period. The gradual release of COD over several years is again seen in the unprocessed cells.

The higher COD values, approximately three times higher than obtained with comparable refuse cells, are due to the increased amount of readily available organic matter in the garbage cell. This indicates the effect of paper and other rubbish in depressing the COD curve.

COD Production - Unprocessed Garbage

The curves of grams COD per sampling period, Figure 55, exhibits the same shape as the COD concentration curve in that it starts out high initially but falls to a low and fairly constant level toward the end of the observation period.

Conductivity and Other Specific Ions - Unprocessed Garbage

The relationship between COD and conductivity is not as apparent with with the garbage cells as it was for the combined refuse cells (Figure 56). With the unprocessed garbage cell, the conductivity curve generally increased, whereas the COD concentration curve generally decreased over the test period. There is the tendency for seasonal peaks and valleys to occur, but the general shapes of the curves are not as closely correlated as they were in the case of the unprocessed combined refuse cells.

As with the other cells, the remaining ion concentration curves follow the conductivity curve very closely. The curves are not presented, but maximum, minimum, and average values are given in Table 48, and correlation coefficients in Table 49. In general, the pH varied inversely as the COD

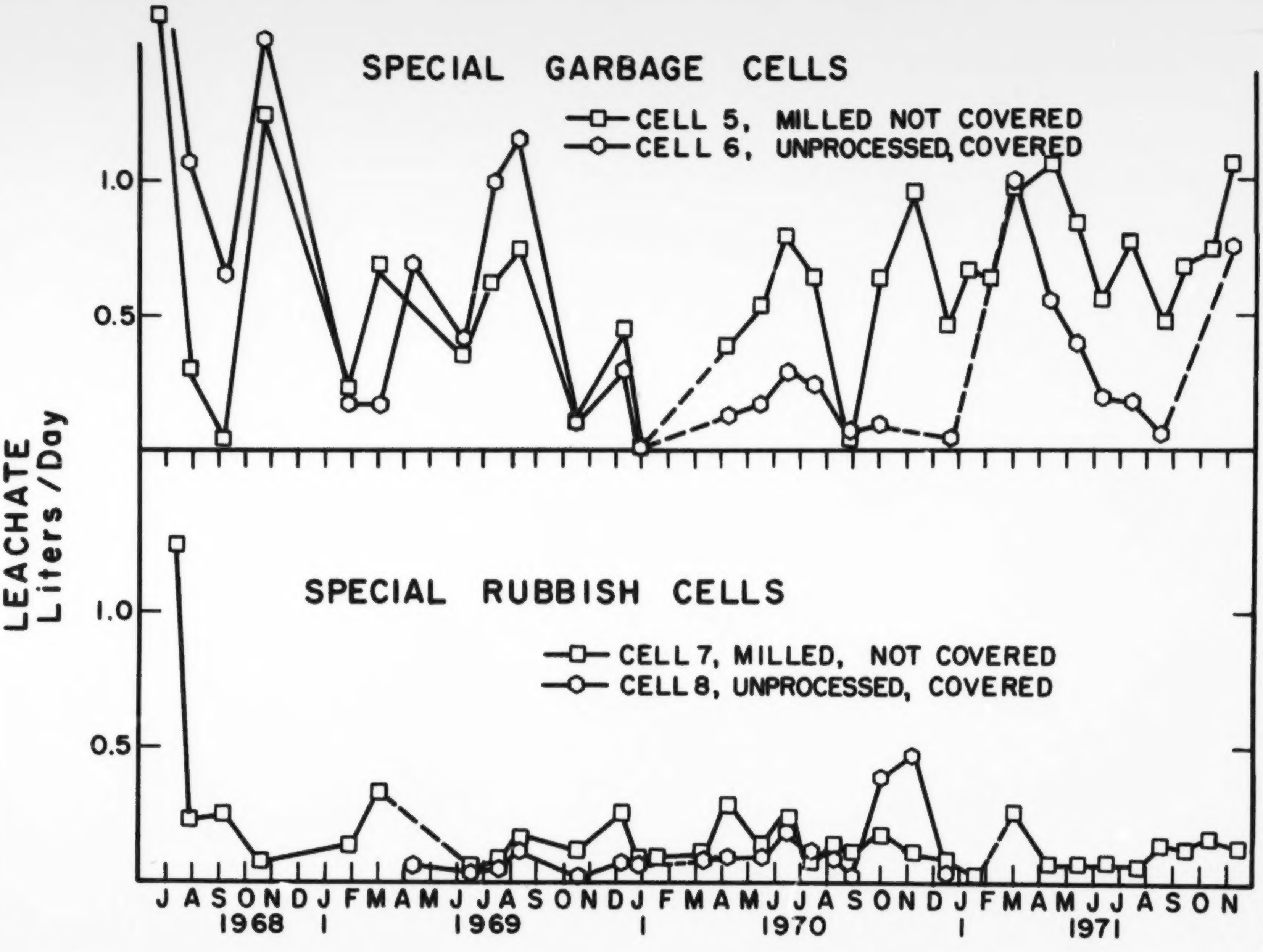


Figure 53. Leachate Production, Special Cells

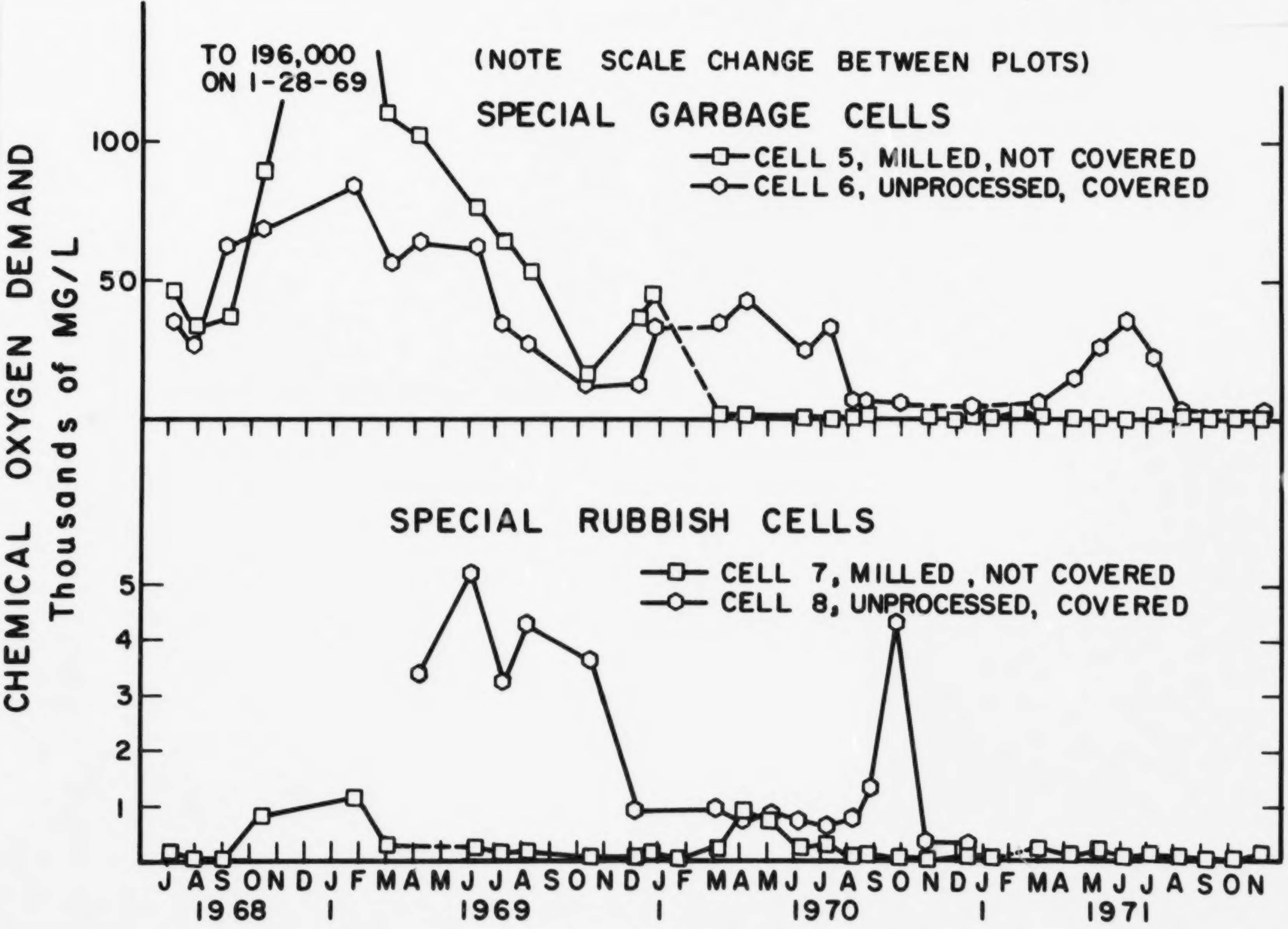


Figure 54. Leachate Chemical Oxygen Demand, Special Cells

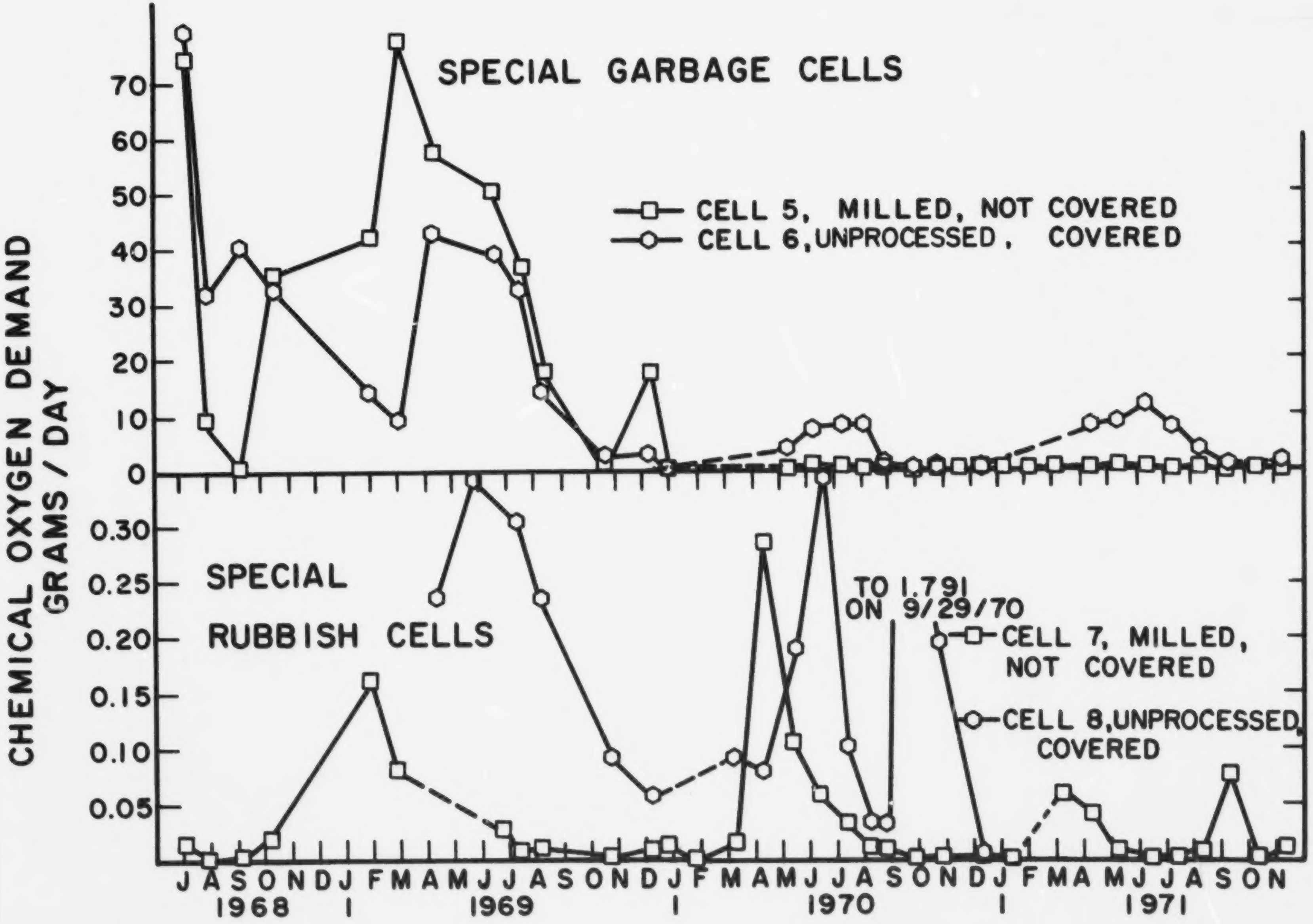


Figure 55. Leachate Grams of COD per day, Special Cells

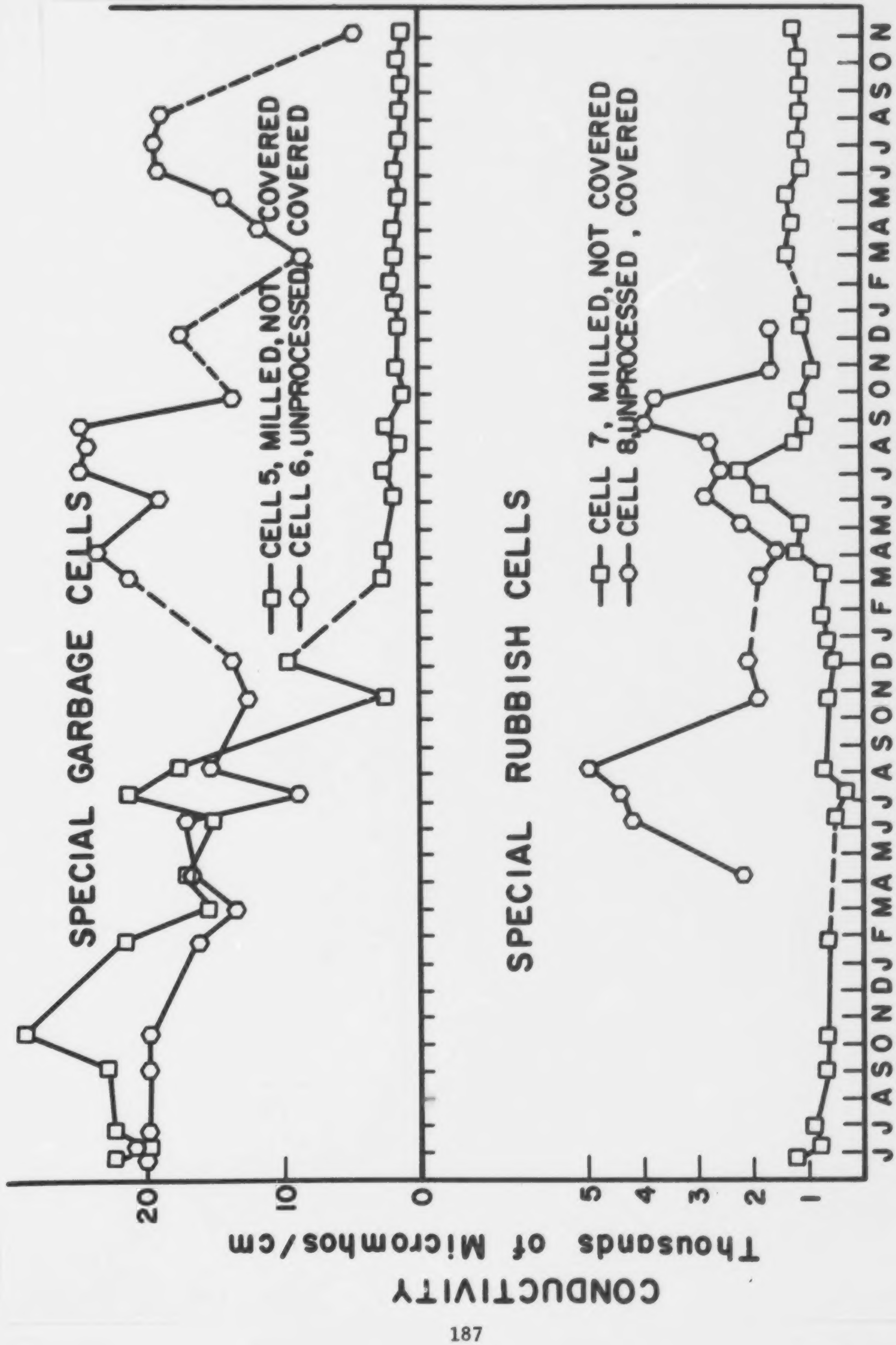


Figure 56. Leachate Conductivity, Special Cells

concentration curve. For Cell 5, the low pH value of 5.5 occurred on July 11, August 4, and December 4 of 1967. The high value of 7.5 occurred on January 13, 1971. The pH tended to rise over the test period.

Leachate Production - Milled Garbage

With the milled garbage cell, as with the unprocessed garbage cell, leachate production was higher when compared with the corresponding combined refuse cell (Figure 53). Again, at least for the initial leachate production, this was due to the higher initial moisture content of the garbage and the absence of paper to absorb and thus retard the flow of water through the cell.

With the milled garbage there seemed to be a small but steady increase in leachate production over the test period. There did seem to be a greater ease of leachate production with this cell, with sharp peaks and valleys resulting from wet and dry periods and other climatic variations. This points to the importance of the paper fraction to retard and thus dampen the rate of passage of rain through cells until field capacity is reached.

COD Concentration - Milled Garbage

The COD concentration curve of the milled garbage cell is not only striking, but it seems to be particularly indicative of the milled cell situation (Figure 54). The curve has a very rapid rise to a peak concentration and then, just as rapidly, it drops to very low COD values, consistently ranging around 200 mg./l. In several samples, the low values of COD are almost indistinguishable from zero on the plot. These are among the lowest COD levels found with any of the test cells.

Most of the organics that decomposed and/or were leached from the cell were removed during the early portions of the test period. A comparison of the milled garbage curve to the curves of the milled combined refuse cells suggests that most of the COD in leachate produced early in the degradation process is a result of the presence of easily degraded organics - the garbage fraction. The milled combined refuse cells produced lower COD values during this period because they contained less garbage (food waste) than the milled garbage cell. However, the non-garbage fraction present in higher concentrations in the combined refuse cells seems to have had the effect of retarding or prolonging the production of COD in leachate. This may be accomplished by the presence of organic matter which is not so readily degradable and which takes longer to leave the refuse as COD in leachate, and by "diluting" the readily degraded garbage fraction.

COD Production - Milled Garbage

The COD production curve shown in Figure 55, also indicates the ease of degradation and/or leaching of the garbage fraction of solid waste. There is initially a rapid rise to a peak COD production rate followed by an equally rapid decline to a small and virtually insignificant production rate of COD. This indicates again that the garbage fraction for milled refuse contributes mainly to the early period of COD production and after that it assumes an almost negligible role.

Conductivity and Other Specific Ions - Milled Garbage

The conductivity curve for the milled garbage cell is shown in Figure 56. It follows the shape of the COD concentration curve with high values followed by reductions to low and rather constant levels.

Again the other ion concentrations followed the conductivity curve quite closely. Summary data are given in Tables 48 and 49. Also, the pH curve was found to vary inversely with the COD concentration curve. With cell 6, the low pH value occurred on July 30 and October 19 of 1968, and the high of 8.3 occurred on December 16, 1970. In general pH rose during the test period.

Special Rubbish Cells

Cell Histories

Two cells were constructed using specially collected rubbish (combined refuse without garbage). Cell 8 was constructed of unprocessed rubbish and covered with 6 in. of earth. Cell 7 was constructed of milled rubbish and was not covered. Both cells were virtually free of outside influences until the beginning of 1971, when sharp increases in leachate and COD concentrations for cell 8 indicated the influence of the encroaching landfill operation. Cell 8 is close to cells 12 and 14, which were similarly affected the previous spring.

Leachate Production - Unprocessed Rubbish

Leachate production from the unprocessed rubbish cell, cell 8, began several months after the rest of the test cells began producing leachate regularly. The data are presented in Figure 53. When production did take place it was initially at a low rate, followed by a gradual rise to the point where outside influences affected the cell and negated any further analysis (early 1971). A possible reason for the relatively late initiation of leachate production is the cell construction date. Cell 8 was constructed in March 1968, and so was one of the last cells built. Because it was composed of large amounts of paper, it took longer for the moisture front to pass through the cell than with the other test cells.

COD Concentration - Unprocessed Rubbish

COD concentration levels from the unprocessed rubbish cell are low when compared with unprocessed, combined refuse cells (Figure 54). This corresponds with previous comments explaining the high initial COD levels in the garbage cells, since rubbish contains less easily degradable organic matter than either the garbage or combined refuse cells. The COD curve exhibits the characteristic seasonal fluctuations of the unprocessed cells. The curve has a downward tendency after the peak which may be due to the relatively hard-to-degrade organics present in large amounts in the rubbish. What easily degraded organics there were in the rubbish were leached out during the first peak, leaving relatively hard-to-degrade organics behind.

COD Production - Unprocessed Rubbish

The gram-COD curve, Figure 55, exhibits the same characteristics as the COD concentration curve, with seasonal peaks and valleys plus a general downward tendency. Since leachate production is fairly consistent, the low levels of production again point out the presence of the relatively hard-to-degrade constituents of the rubbish fraction.

Conductivity and Other Specific Ions - Unprocessed Rubbish

The conductivity curve for the unprocessed rubbish cell, Figure 56, was found to correspond to the general shape of the COD concentration curve. The curve exhibits the characteristic seasonal variations and the more gradual decline in magnitude found with other unprocessed refuse cells over the test period. The conductivity range is lower than that of the other unprocessed cells, again indicating the smaller contribution of the rubbish fraction to pollutant production.

The specific ion curves, as with the other cells, followed the general shape of the conductivity curves. The data are summarized in Tables 48 and 49. The pH with the unprocessed rubbish cell was essentially neutral, although a slight inverse relation with COD and conductivity could be detected. The low pH of 6.5 occurred on August 21, 1970, and October 5, 1971. The high of 7.7 occurred on October 19, 1968.

Leachate Production - Milled Rubbish

Leachate production from the milled rubbish cell was very constant except for the first point (Figure 53). Initial production was slightly higher than production later in the test period; however, the decrease was so small as to be virtually insignificant.

COD Concentration - Milled Rubbish

The COD concentration curve, Figure 54, exhibits the initial peak seen in the other milled cells, though the magnitude is very low compared with the other cells. COD production after the initial peak was so low as to be almost nonexistent until approximately a year-and-one-half after production began, when a second smaller COD rise occurred. Second peaks were experienced with all the milled cells but were not delayed as long after the initial peak as in this cell. This is again indicative of the poorer degradation characteristic of the rubbish fraction of solid waste.

COD Production - Milled Rubbish

The grams-of-COD curve is shown in Figure 55. It follows the general shape of the concentration curve. Again the initial peak is followed by secondary peaks. Magnitudes of COD production are again very low when compared with other cells, and the production decrease with time was not as pronounced as with the milled garbage or combined refuse cells.

Conductivity and Other Specific Ions - Milled Rubbish

With the milled rubbish cell the direct relationship between the conductivity and COD concentration curves was not as pronouned as with the other cells (Figure 56). The conductivity curve had a slight tendency to increase throughout the test period, as opposed to the COD concentration curve which generally decreased throughout the test period.

The other specific ion concentration curves usually exhibited level or slightly downward tendencies. The data are summarized in Tables 48 and 49 . Correlation coefficients were, therefore, quite small with only alkalinity approaching significance in correlation with conductivity. This is because only the alkalinity curve showed an upward tendency as did the conductivity curve. For the other variables the magnitudes of the values were small and the differential changes with time were also so small that random errors could easily have masked any relationships between the variable in question and conductivity. As with the unprocessed rubbish cell, the pH curve is nearly neutral throughout the entire period, going slightly acidic only during periods of COD rises. The low pH of 6.0 on April 5, 1971, while the high of 7.45 occurred on December 16, 1970.

Gas:

Originally 13 cells were equipped with gas probes, but destruction of cells by landfilling and fires reduced the number of cells useful for long-term gas data analyses to four. These include cell 3 - milled and combined refuse; cell 7 - milled rubbish; cell 8 - unprocessed rubbish; and cell 22 - unprocessed combined refuse. There was a period, indicated by the break in the curves, when the gas composition data were not collected. This was done in order to concentrate on the leachate data, as there was some evidence that gas composition was more dependent on the presence of cover than on whether the refuse was milled, and because early gas results were so variable that no trends could be established.

Four gases were measured in terms of percent by volume of the gas present. These gases where O_2, N_2, CO_2, and CH_4. As would be expected, the O_2 concentration was higher in the probes closer to the surface and the CH_4 concentration was higher at the deepest levels within the cells. At all depths sampled there was always a small concentration of O_2, probably indicating sampling or experimental error, since the large CH_4 concentrations at the greater depths indicate anaerobic conditions. For purposes of this discussion only the results from the probes at the greatest depths will be given, as found in Figures 57 and 58. Data from other depths were superfluous and compared well with the data shown here.

In general, it is noted that O_2 accounts for a larger percentage earlier in the cells' histories than later. Likewise, CO_2 and CH_4 represent a smaller percentage in the earlier period than later. This indicates, in part, a change from aerobic to anaerobic conditions within the cells. Note again that the presence of some O_2 at very low concentrations is not thought to be significant, for small amounts of air were undoubtedly introduced during sampling and analysis. N_2 may be determined by difference from the data given in the figures.

CO_2 concentration, unlike that of the other gases, did not fluctuate quite as drastically over the test period. Since CO_2 production should rise as degradation increases, e.g., in the summer months, some CO_2 gas must be soluabilized into the leachate. Further, since alkalinity is a

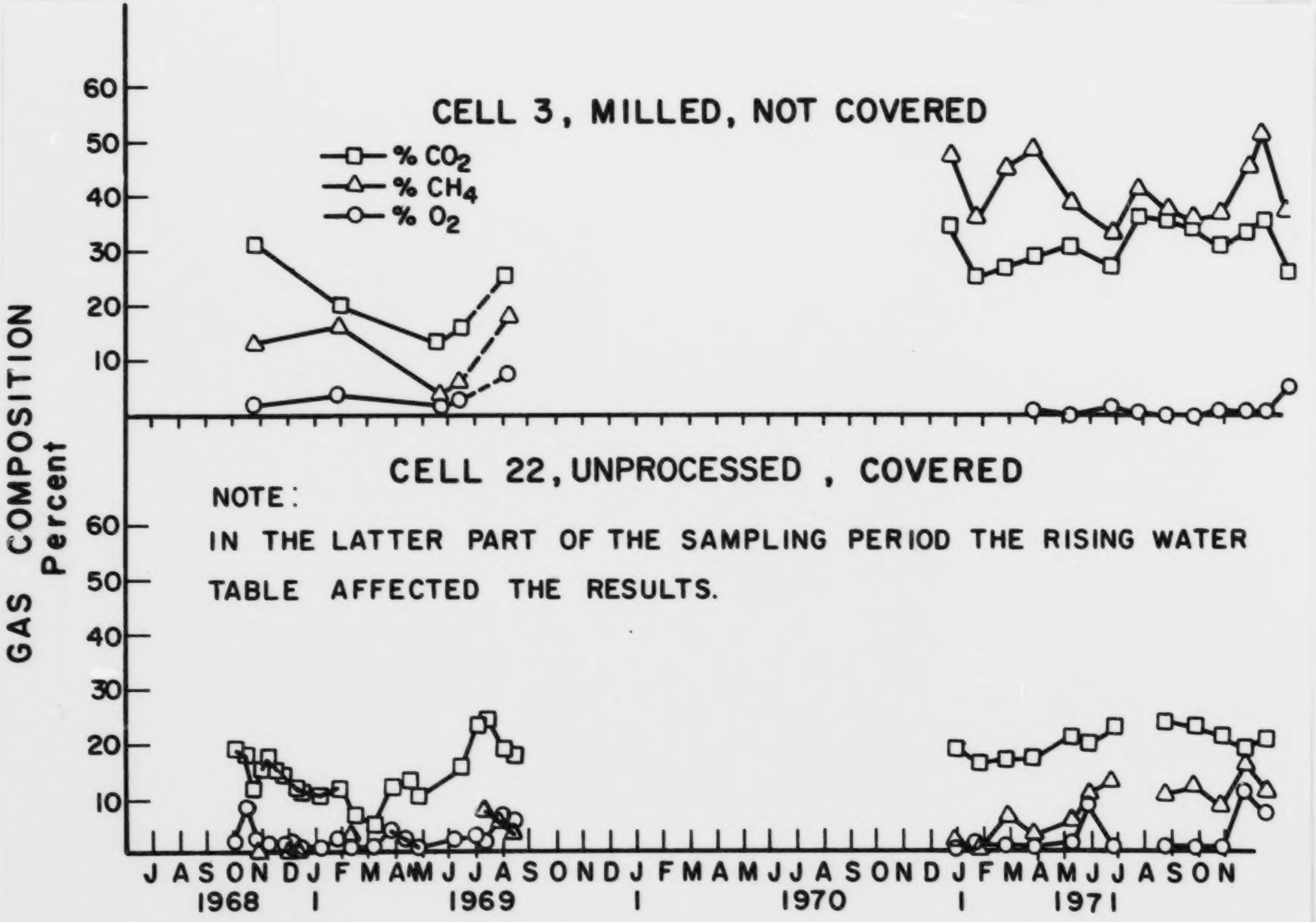


Figure 57. Gas Data, Combined Refuse Cells

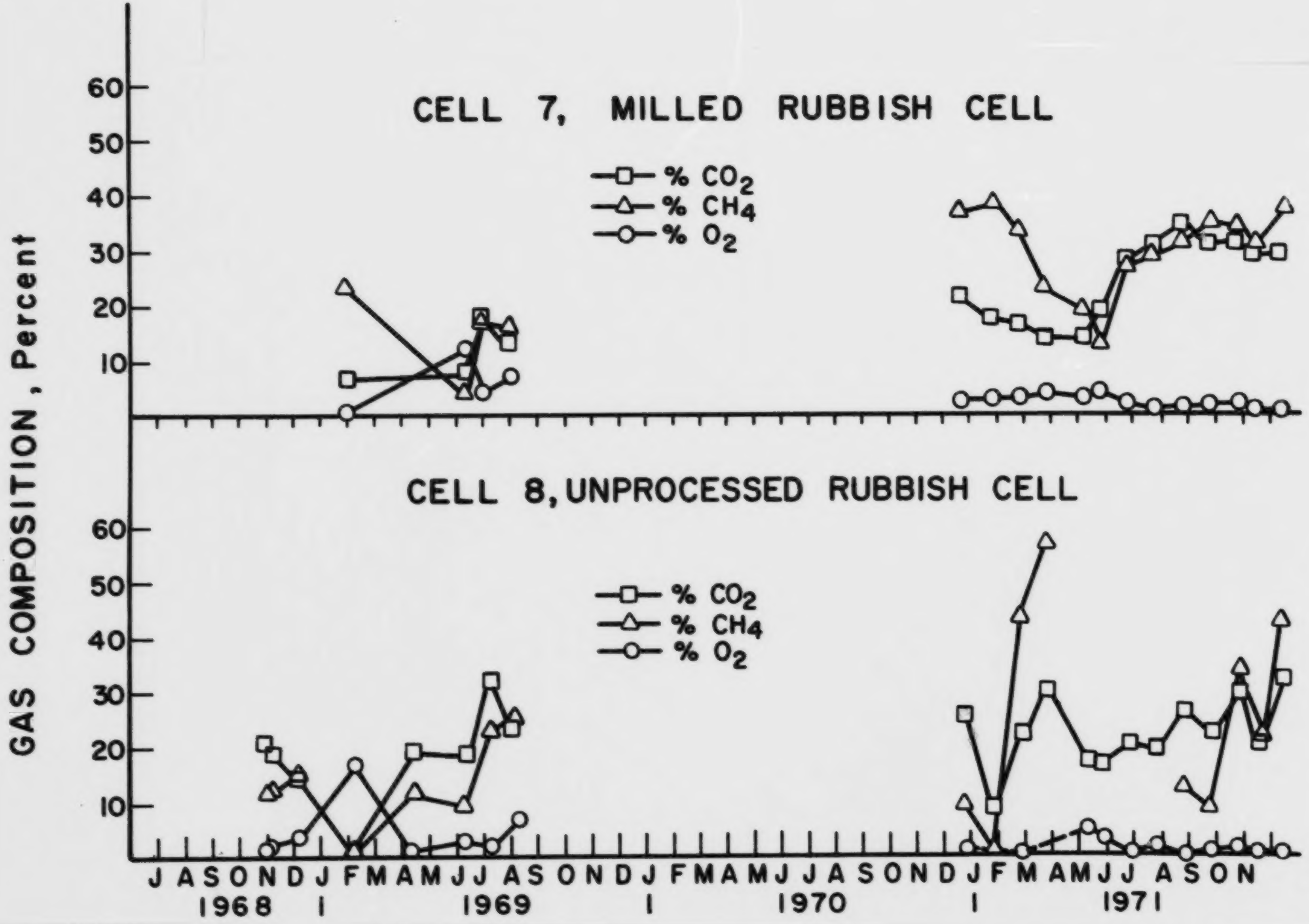


Figure 58. Gas Data, Special Cells

measure of the ability of leachate to absorb acids, and since the alkalinity was observed to increase during periods of increased degradation, there is evidence that a possible increase in CO_2 solubilization also occurred during periods of increased activity. This helps explain the relatively constant CO_2 concentration values observed in the gas analyses.

It is also interesting to note that CO_2 concentrations seem to vary much more widely in the two rubbish cells than in the two combined refuse cells. Since leachate production was lower, and leachate produced contained less contaminants in the rubbish cells, it is possible that the leachate produced in the rubbish cells was not sufficient to solubilize all of the CO_2 produced at all times, thus leading to the variation.

Another interesting point with the gas curves begins with the observation that as the O_2 percentage increases the CH_4 percentage decreases. This occurred several times during the spring thaw and after periods of heavy rainfall, indicating that O_2 is carried into the cell by the percolating water and retained in the cell for a short period of time. This inhibits CH_4 production.

Figure 57 indicates that the only major difference in gas composition between cells 3 and 22 was the CH_4 content, which was markedly higher in the case of cell 3 (milled, not covered). This corresponds with the leachate results, which indicate that milled refuse undergoes decomposition more quickly. There are no such marked differences between cells 7 and 8, as shown on Figure 58, corresponding to the leachate results which indicated that neither cell was undergoing rapid decomposition.

A major problem in interpreting gas composition results was encountered early in the study. It was apparent that with most cells, the milled uncovered cells had higher O_2 and N_2 concentrations and lower CH_4 and CO_2 concentrations than the unprocessed covered cells. Unfortunately, the data shown in Figures 57 and 58 do not show this because these data are from the few cells which did not. This general observation was difficult to relate to the leachate results, which indicated that the milled cells decomposed more quickly. The conclusion was that the presence of cover may be of overriding importance, limiting passage of air in, and CO_2 and CH_4 out of, the cells. The need for gas production data, as opposed to gas concentration data, was the reason for the Biotron studies reported in Section VI-C. The lysimeter bed degradation studies, reported elsewhere, suggest a similar conclusion with regard to the effect of soil cover on gas composition.

Apparent Mechanism of Decomposition:

The data of this study illustrate some basic principles which can serve to aid in understanding and interpreting the results. The rate and extent of degradation and the removal of matter from a landfill are dependent on a variety of interrelated factors. The two basic mechanisms resulting in removal of matter are physical or chemical leaching and biological decomposition. Physical and chemical leaching is brought about by the flow of water through refuse by which matter is rinsed or dissolved out.

Biological decomposition refers to the degradation of refuse to leachable matter or gas by biological activity. These two basic mechanisms are dependent on the following:

1. Presence of water.

   Provided there is infiltration of water through the top layer of refuse or earth cover, as occurs in a humid climate, water will reach and wet the refuse. Once the refuse can hold no more water and reaches field capacity, water flows downward through each successive layer of refuse and finally enters the underlying soil or the water table. Such water is called leachate. Water brings about physical and chemical leaching and, in addition, is a prerequisite for biological activity. As evidenced by cell 2, which received a large dose of water in the spring of 1970, physical leaching can remove large quantities of matter from apparently mature refuse volumes.

2. Temperature.

   Both the ambient or outdoor temperature, as well as the refuse temperature, affect the rate of decomposition. The greater the temperature within the refuse, the more quickly biological activity proceeds. The ambient temperature is important as it modifies the refuse temperature.

3. The presence of air.

   In the presence of air, aerobic decomposition takes place, which may be characterized by rapid activity, producing sufficient heat to raise the temperature perhaps 30 to 40° F above ambient at a 6 ft. depth. If the rate of oxygen use exceeds the rate of replenishment, the refuse becomes anaerobic and a new group of organisms predominates. At first organisms which can tolerate the presence of some oxygen become important, and these characteristically begin the anaerobic decomposition of the organic matter. In so doing, partially decomposed organics are made available to the leachate, resulting in high COD levels. Since some of these organics are acidic, the pH drops. This is called first-stage anaerobic decomposition.

   As decomposition proceeds further and all oxygen is depleted, the methane-forming bacteria predominate. These organisms are able to decompose organic matter more completely to CH_4 and CO_2. At this point the COD of the leachate decreases, the pH rises, and CH_4 is actively produced. This is called second-stage anaerobic decomposition and is commonly associated with little or no heat release or temperature rise.

4. The effect of milling and mixing.

   Milling is thought to enhance the rate of physical-chemical leaching and biological decomposition by increasing the surface area of the refuse, exposing more of it to biological and leaching activity, and by avoiding pockets of relative inactivity through mixing. Further, water flows more evenly through the entire volume of refuse if it is milled, rather than channeling through and contacting only portions of the refuse as is more likely with unprocessed refuse. This also brings about more uniform decomposition. Finally, by breaking up large items such as cabbage heads, telephone books, etc., during milling, the refuse can decompose more uniformly, so that a larger fraction of the readily removable matter is extracted from all of the refuse quickly, leaving a relatively inert mass behind.

CONCLUSIONS

The conclusions of this work, subject to the conditions and limitations of the test cells, are as follows.

1. Organics were removed from milled refuse by leachate at a faster rate and over a shorter period of time than with unprocessed refuse. This phenomenon resulted from the grinding and mixing of refuse, which produced a product susceptible to uniform degradation and leaching.

2. The unprocessed cells were more influenced by seasonal changes than were the milled cells. Both types evidenced rises and falls in the curves due to seasonal changes, but the unprocessed cells were more strikingly affected.

3. Leachate production rates with milled cells seemed to be higher when compared with the unprocessed cells. This conclusion is tentative, however, because an accurate water balance could not be made with the test cells. The change in leachate production is thought to be more a function of cover than whether the refuse is milled. The role of cover, however, could not be determined in this study.

4. The pH curves showed an inverse relationship with COD concentration and production curves, a relationship related to the two stage anaerobic degradation process. Initial pH levels for the milled cells were acidic and rapidly approached neutrality. In the unprocessed cells the pH curve had a general trend toward lower (more acidic) pH levels with time.

COD production curves for the milled cells showed an initial high rate and then dropped off almost to zero. With the unprocessed cells the COD production curves began at a lower level than the milled cell curves and then increased slightly or stayed constant in subsequent years. Consequently, it was commonly observed that the milled cell produced COD in leachate more actively than the unprocessed cell for one year or so, while the comparable unprocessed cell produced larger amounts of COD than the milled cell in subsequent years.

These curves indicated that, for milled refuse, decomposition proceeds more quickly and soon reaches a steady state level where few leachable substances are released. During the initial high COD period, the low pH suggests that aerobic and first-stage anaerobic decomposition is resulting surface area of the refuse, exposing more of it to biological and leaching activity, and by avoiding pockets of relative inactivity through mixing. Further, water flows more evenly through the entire volume of refuse if it is milled, rather than channeling through and contacting only portions of the refuse as is more likely with unprocessed refuse. This also brings about more uniform decomposition. Finally, by breaking up large items such as cabbage heads, telephone books, etc., during milling, the refuse can decompose more uniformly, so that a larger fraction of the readily removable matter is extracted from all of the refuse quickly, leaving a relatively inert mass behind.

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These curves indicated that, for milled refuse, decomposition proceeds more quickly and soon reaches a steady state level where few leachable substances are released. During the initial high COD period, the low pH suggests that aerobic and first-stage anaerobic decomposition is resulting in partially decomposed and leachable organic substances, including organic acids. A few months later the pH rises to near neutrality and the COD drops, suggesting that second-stage anaerobic decomposition is predominant, where the organics, including the organic acids, are more completely degraded, and more CH_4 is produced. The general fall in the pH curves, and the rise in the COD curves for the unprocessed refuse cells, suggests that these cells took longer to undergo decomposition and could not be characterized as having attained mature second-stage anaerobic decomposition to any great extent.

5. The conductivity curves show that inorganics are removed from milled cells more quickly than from unprocessed cells, although the difference is not nearly as pronounced as in the case of COD. Again, milling and mixing seem to play an important role because the smaller particle sizes and the more active decomposition processes expose the inorganics to more leaching action. Conductivity and other specific ion curves generally followed the shapes of the related COD concentration curves except in the case of the special cells.

6. From the special cells the following points were noted. With the garbage cells, where readily decomposable organics were available, the rate of removal of organics by leachate from the milled cell was much faster than with the unprocessed cell. Both cells showed higher concentrations of organic matter than the comparable combined refuse cells. This is due to the ready availability of organics. The unprocessed cell showed the same tendency to undergo active leaching longer than the milled cell, as found with all other test cells, but never at as high a level as the milled cell during its peak production period. The milled cell curve showed an extremely high level of COD initially, but dropped rapidly to consistently low levels which were lower than the unprocessed cell during this period. Both garbage cells dropped more quickly to low COD levels than did comparable combined refuse and rubbish cells.

Leachate production from these cells fluctuated widely, possibly indicating the relative ease of passage of water through the cell by the dependency of leachate production on precipitation.

Both the milled and the unprocessed rubbish cells produced relatively insignificant amounts of oxygen-demanding substances in the leachate. This corresponds to the relatively small amounts of putrescible matter present in the rubbish fraction of the solid waste used to construct the test cells. The low COD levels are especially striking when compared to the garbage cell results. The leachate volume curves indicated a relatively constant rate of production of leachate from both cells, suggesting more independence between leachate production and incident precipitation than found with combined refuse or garbage cells. This in turn suggests that the rubbish fraction served to retard the free passage of leachate through the cell. With both rubbish cells, the production of contaminants in leachate continued over a longer time and at a more uniform rate than with the garbage or combined refuse cells, but at much lower concentrations.

7. Leaching played an important role in removal of organics from the cells, as evidenced by the dosing of cell 2 with water while a nearby fire was being extinguished, and also by the overall shape of the milled cell curves. In examining the COD production curves, one can see an initial

high point of COD production which drops off rapidly. This observation, plus the rinsing of matter from cell 2, suggests that some of the organic material left in the cell after the peak is not fully degraded, but simply has not been rinsed out.

8. The gas composition data shows that anaerobic degradation, as evidenced by increased amounts of methane, plays a larger and larger role in the removal of organics as the cells mature. Because of the nature of the test facility, it is not possible to compare the results from the milled and unprocessed cells, as the effects of milling cannot be separated from those due to the cover. For example, a low CH_4 level could be due to less CH_4 production, or the ease of loss of CH_4 to the atmosphere if no cover is provided. CO_2 data is not meaningful for these same reasons plus the overriding effect of the solubility of CO_2 in water. Thus, the flow of leachate may regulate the CO_2 concentration more than any other factor.

VI-B - Lysimeter Field Studies

INTRODUCTION

During review of the Olin Avenue decomposition studies, it was decided that a more definitive analysis of certain characteristics of milled and unprocessed refuse was needed. Various problems unforeseen at the beginning of the Olin project limited the conclusions that could be drawn from the data obtained. In the construction of the cells, for example, no attention was paid to the size, shape, or amount of refuse in each cell. This meant that no results could be drawn as to leachate and/or pollutional load produced by the refuse on a per-weight basis, and that no water flow balance could be made. Also, cells were not identically equipped with gas, temperature, moisture, and leachate collection instrumentation and were constructed at different times of the year; therefore direct comparisons could not be made. Finally, the ongoing operation of filling the surrounding landfill site covered several of the cells with refuse, precluding further use of their data. Initially this caused problems with one cell but finally it meant termination of the entire project.

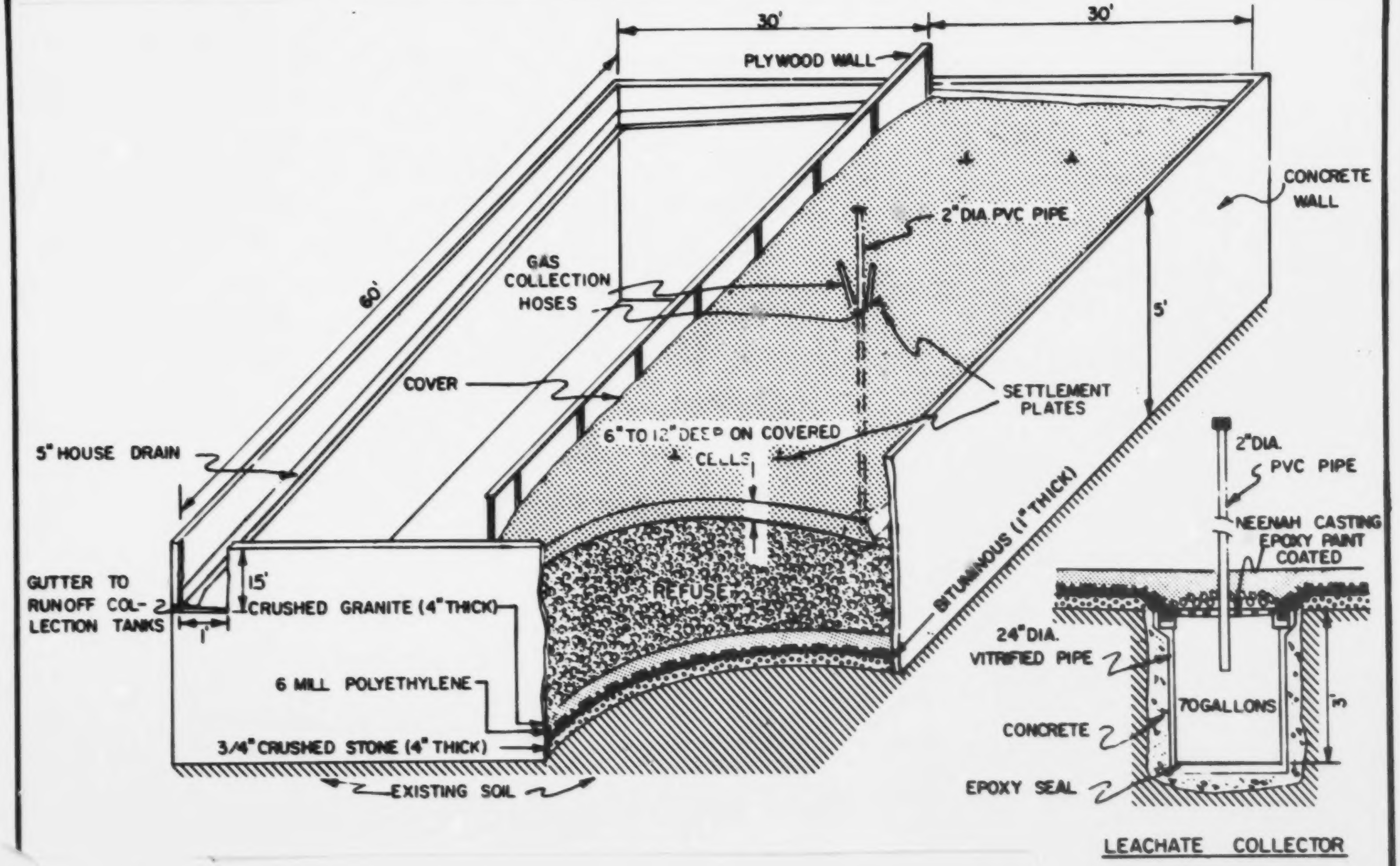
OBJECTIVES

The primary objective of the lysimeter portion of the project was therefore to isolate various refuse cells from the outside interferences mentioned above. With this accomplished, the second objective was to obtain a direct comparison of pollutional loads from milled and unprocessed refuse. Third, because of present regulations on the operation of sanitary landfills, the effect of soil cover on degradation and pollution loads from refuse was to be determined. Finally, a water budget was kept to determine the percentages of precipitation which go to runoff, evaporation, and infiltration (leachate).

LYSIMETER BEDS

Construction:

With consent of the Oscar Mayer Company, two obsolete sludge-drying beds at their waste treatment plant were converted to four test cells (Figure 59). The two beds, measuring 60 x 60 ft. with 1-ft. thick concrete walls were excavated to a depth of approximately 5 ft. The beds were divided by wooden partitions to obtain a total of four cells. A 4-in. crushed stone base and 1-in. asphalt cover were sloped to the center of the cells. At the center a 24-in. vitrified clay pipe was inserted to serve as a collection trap for leachate. The spigot end of the pipe was sealed with concrete and covered with epoxy paint to prevent any chemical reactions with leachate from occurring. An iron stormwater manhole cover was then placed in the bell to support the refuse and to prevent reaction with the leachate. A plastic tarp was placed on the asphalt floor and along all walls to insure leachate containment and to further isolate the leachate from outside interferences (Figure 60). Four inches of coarsely crushed granite rock (greater than 1 inch


30'
30'
PLYWOOD WALL
CONCRETE WALL
2" DIA. PVC PIPE
GAS COLLECTION HOSES
60'
5'
COVER
SETTLEMENT PLATES
6" TO 12" DEEP ON COVERED CELLS
5" HOUSE DRAIN
2" DIA.
PVC PIPE
NEENAH CASTING EPOXY PAINT COATED
BITUMINOUS (1" THICK)
REFUSE
15'
GUTTER TO RUNOFF COL-LECTION TANKS
1'
CRUSHED GRANITE (4" THICK)
6 MILL POLYETHYLENE
3/4" CRUSHED STONE (4" THICK)
EXISTING SOIL
24" DIA. VITRIFIED PIPE
70 GALLONS
CONCRETE
EPOXY SEAL
LEACHATE COLLECTOR
ALL BLACK TOP SURFACES SLOPED TO COLLECTOR

Fı 59. Typical Lysimeter Bed Cross-Section

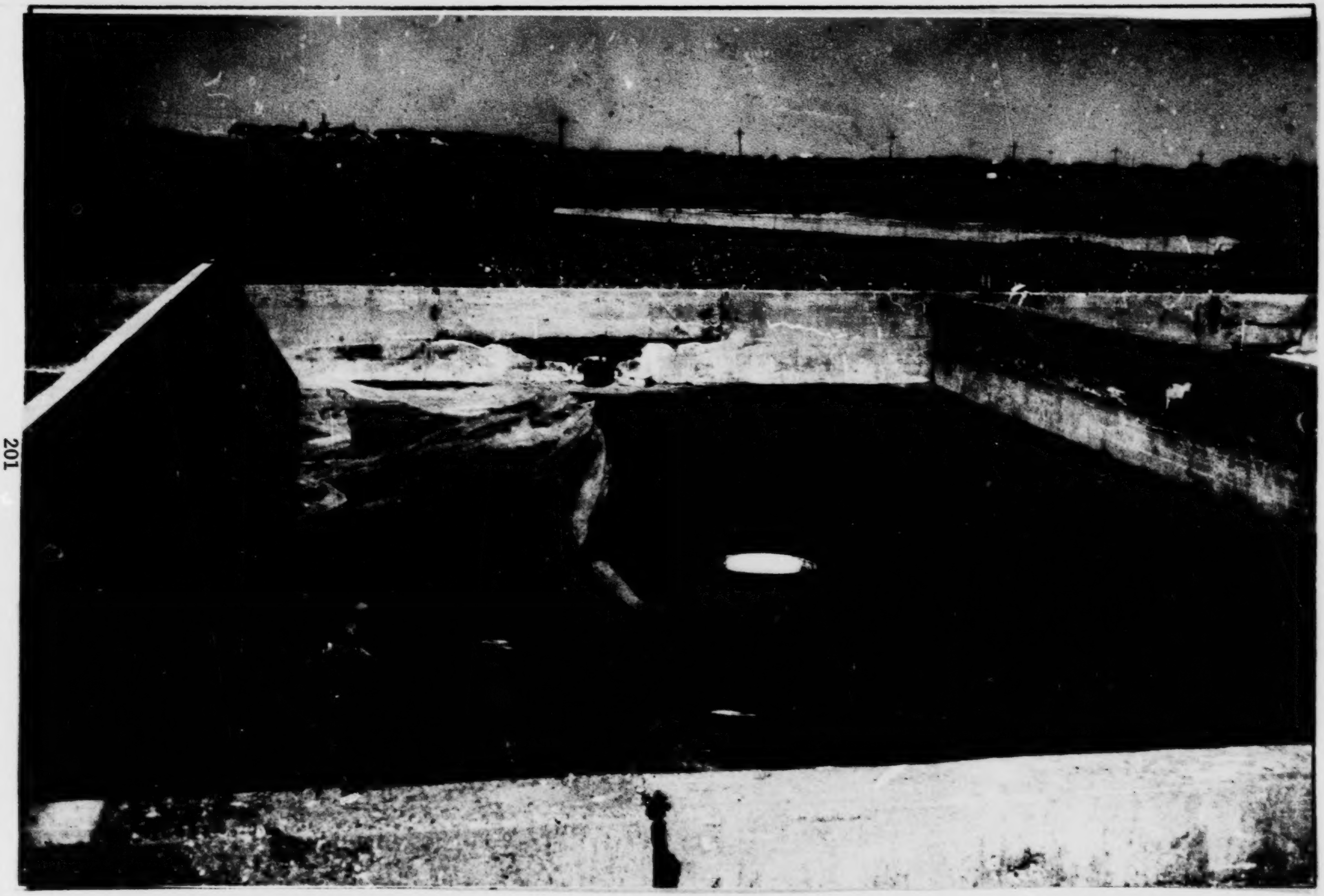


Figure 60. Lysimeter Bed Showing Bituminous Layer and Reservoir While Plastic Sheet was Being Placed

in diameter) was then placed over the entire floor of the cells to facilitate leachate travel to the collection trap and to prevent leachate ponding in the cells. Granite was used because lab tests conducted by University of Wisconsin personnel indicated minimal interaction with leachate. A 2-in. polyvinyl chloride pipe was then inserted into the clay leachate collection trap to a point somewhat above the proposed refuse fill surfaces. This pipe was used to draw leachate from the collection trap. A 3/4-in. length of garden hose was also inserted into the collection trap to the surface.

Four cells (Figure 62) were filled, during the period September 14 to September 18, 1970, as follows:

CELL 1 - unprocessed refuse covered with 6 in. of soil (Figure 63);

CELL 2 - milled refuse covered with 6 in. of soil;

CELL 3 - milled refuse covered with soil after approximately 6 mo.;

CELL 4 - milled refuse left uncovered (Figure 64).

Each cell was filled with approximately 100 tons of refuse as specified above. About 75 tons of sand-clay cover of the kind used in Madison landfills were placed on each of those cells requiring cover.

The refuse and cover in the cells were emplaced and compacted by tracked end loaders used in the city's sanitary landfill operation. The surface on all cells was sloped at 3 percent grade to provide drainage to the edges of the cells. Rain gutters were placed along the periphery of the cells to collect runoff. A clear plastic tarp about 2 ft. wide was placed along and slightly in the gutters and covered with either soil or refuse to aid diversion of the runoff into the gutter and limit passage of runoff around the gutter into the cell to show up mistakenly as leachate.

The rain gutters were extended outside of the cells to a collection and measuring point. Here a 50-gal. barrel and 500-gal. tank were located. The runoff was first directed into the barrel, which served as a more accurate measuring device with smaller rainfalls. With larger rainfalls the runoff spilled over into the tank (Figure 65). These collection vessels were calibrated so that depth measurements could be converted to volumes.

Besides leachate sampling collectors, probes were put into the refuse cells to obtain data on gas production and cell temperature and moisture.

Gas Probes:

In the Olin Avenue study, gas sampling probes were made by using inverted 4-in. diameter plastic funnels connected by rubber hoses to

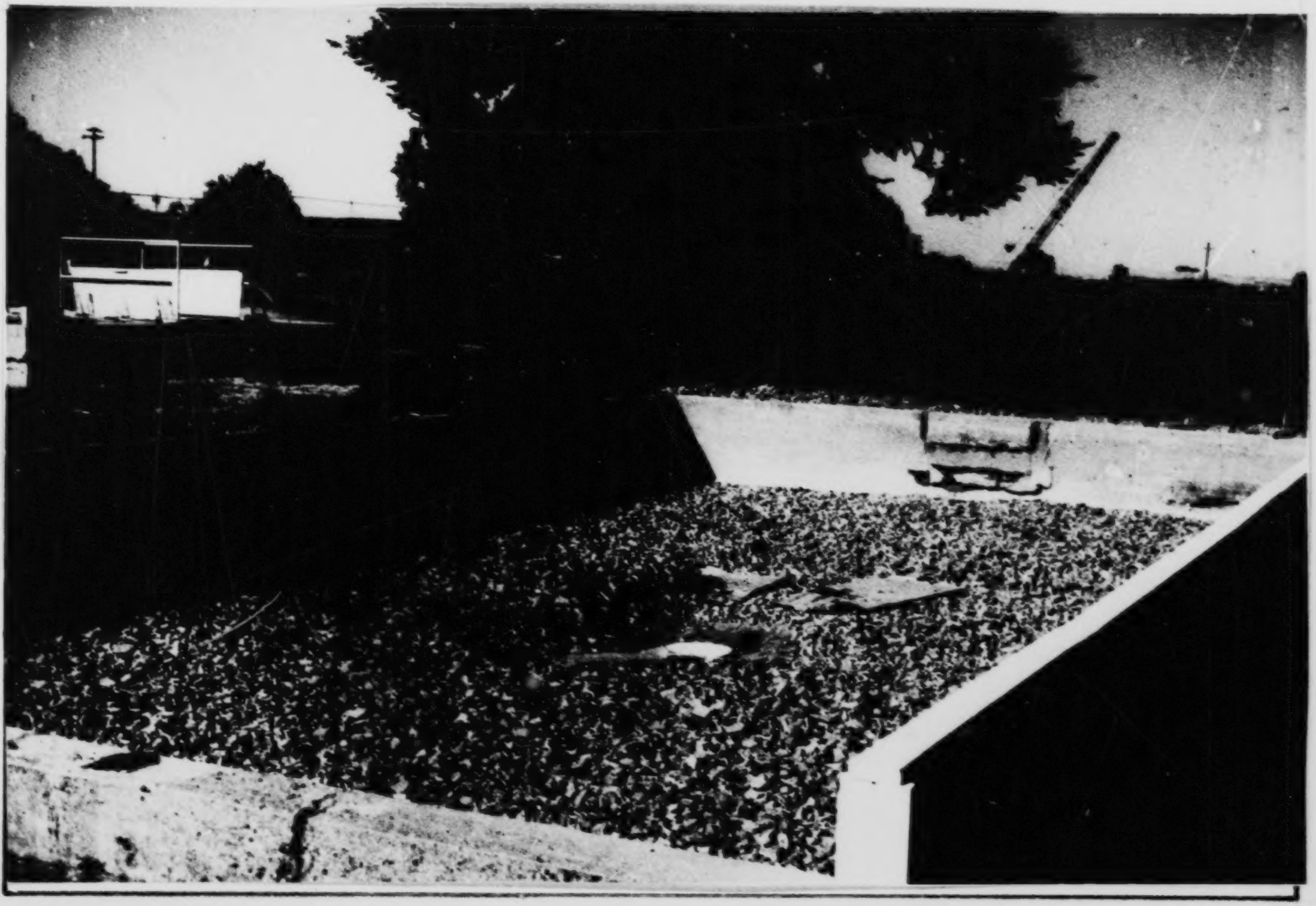


Figure 61. Lysimeter Bed Ready for Filling with Refuse

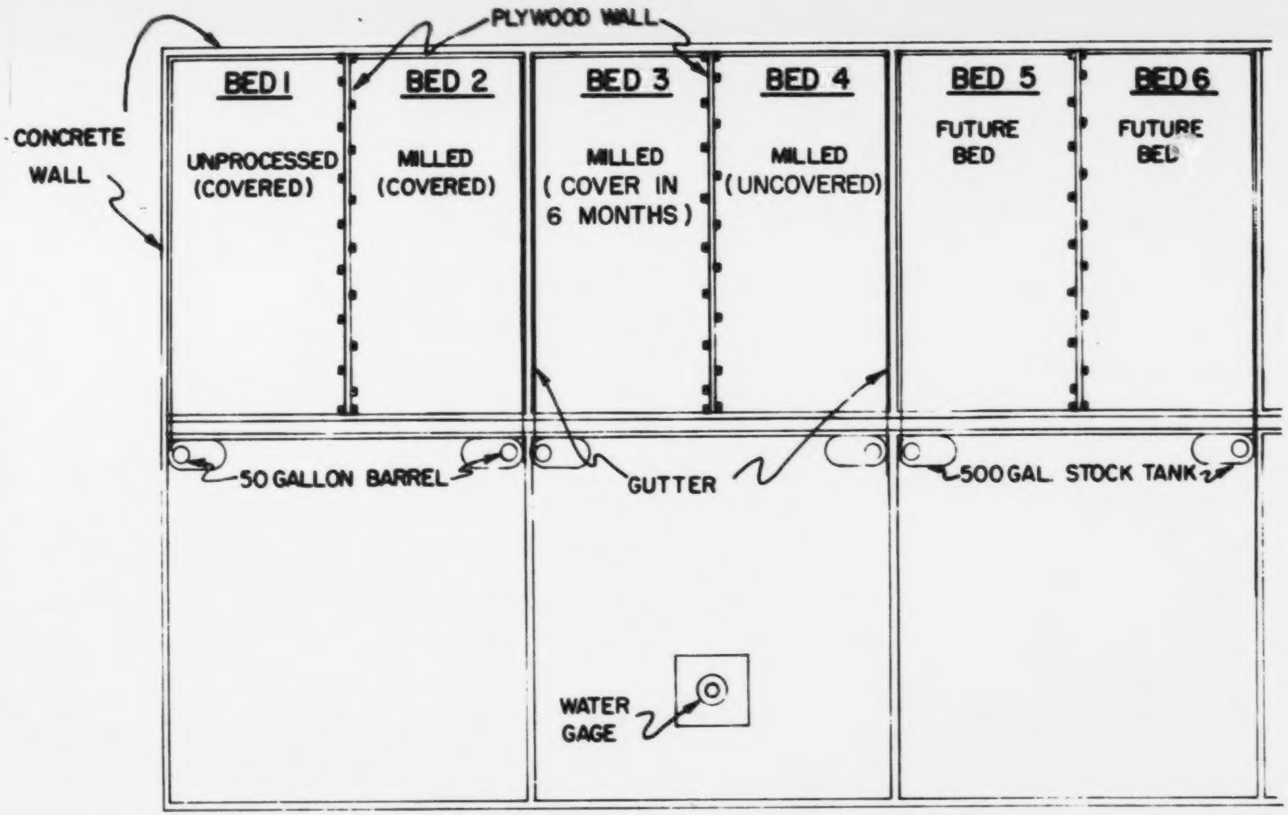

PLYWOOD WALL
CONCRETE WALL
BED 1
UNPROCESSED (COVERED)
BED 2
MILLED (COVERED)
BED 3
MILLED (COVER IN 6 MONTHS)
BED 4
MILLED (UNCOVERED)
BED 5
FUTURE BED
BED 6
FUTURE BED
50 GALLON BARREL
GUTTER
500 GAL. STOCK TANK
WATER GAGE

Figure 62. Diagram of Lysimeter Bed Layout

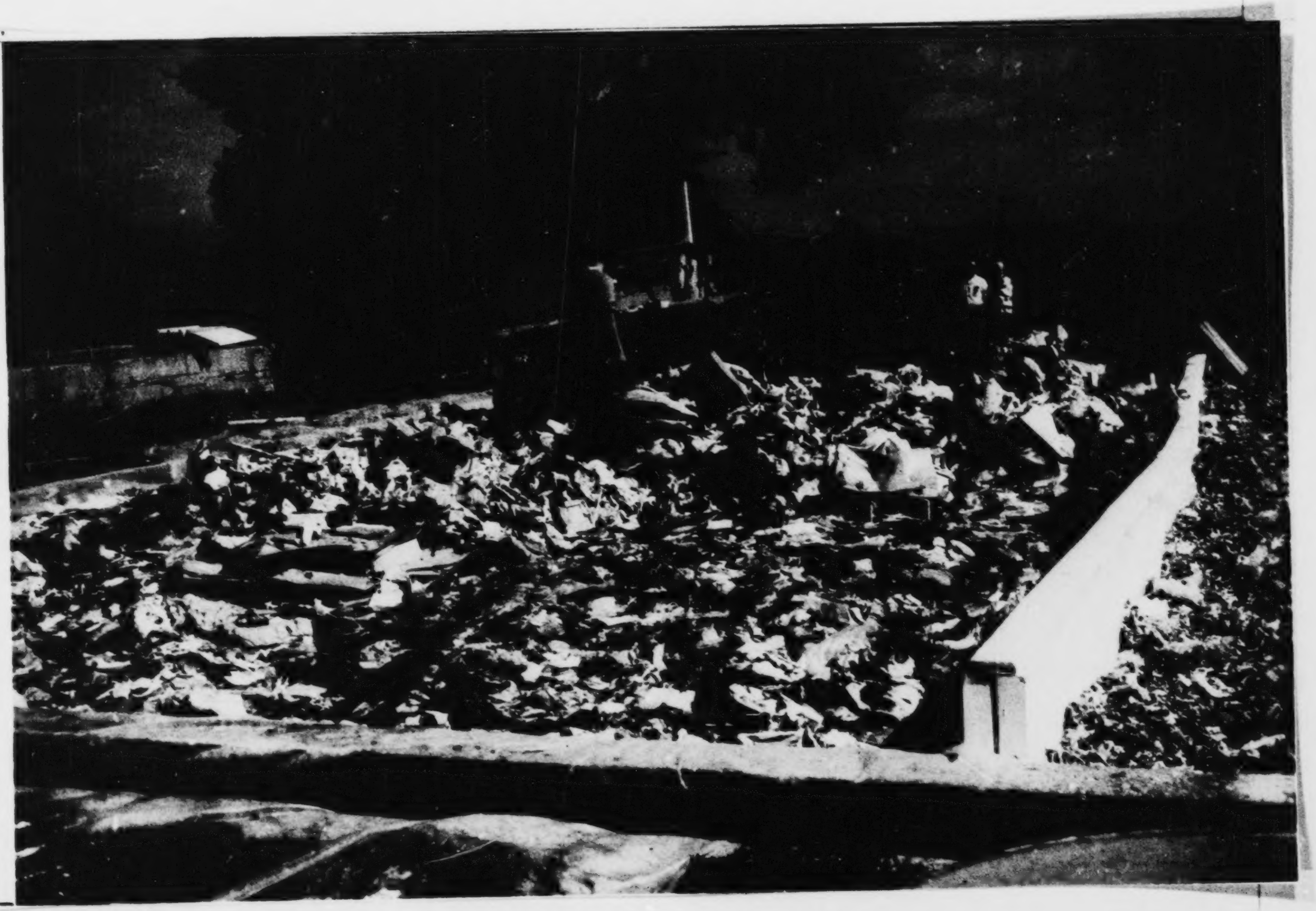


Figure 63. Lysimeter Bed Being Filled With Unprocessed Refuse

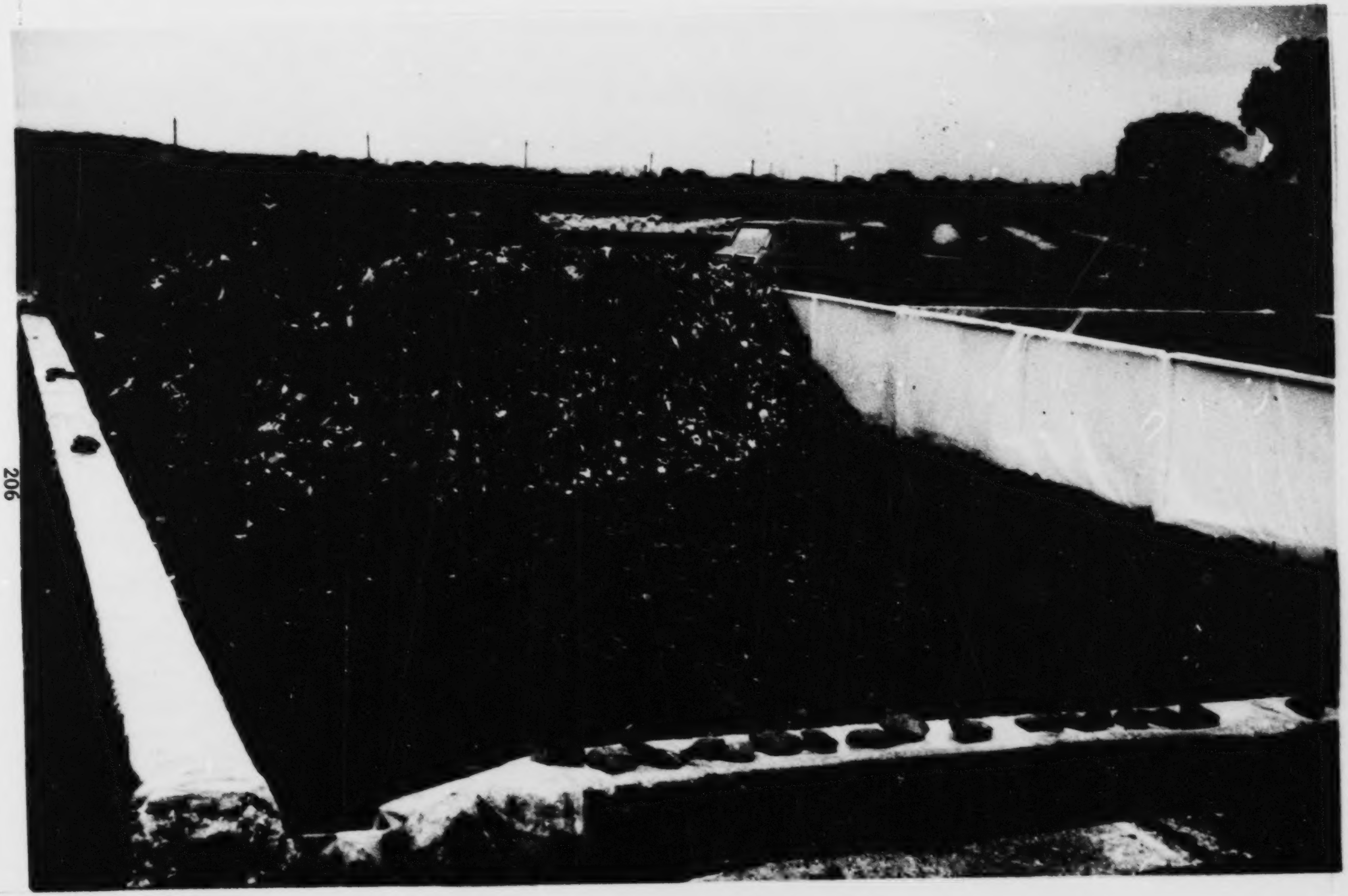


Figure 64. Lysimeter Bed Being Filled With Milled Refuse

Figure 65. Cow Tank and Barrel Arrangement as Used to Collect Runoff From Each Lysimeter

the surface. Trouble in sampling some cells due to plugged funnels led to an attempt to obtain a larger gas trap. This was done by taking a 10-qt. galvanized pail and cutting it in half. The bottom half inverted in the cell would serve as a larger reservoir. The pail was covered with epoxy paint to prevent possible leachate or gas reaction with the metal. Holes were drilled in the side and top to facilitate gas flow in and out so that gas stratification could not occur in the trip and lead to erroneous results. Crushed granite was then placed around the trap to prevent plugging of these holes. A rigid copper tube 6 in long was attached to the inverted bottom of the pail on which a rubber hose was placed. This hose was stoppered at the surface to prevent outside contamination.

2) Temperature and Moisture Probes

All temperature and moisture probles were provided by Soil Test Inc. of Baraboo, Wisconsin. In the Olin Avenue study the temperature portion of the probes worked perfectly but the moisture portion seemed to be erratic. This was due in part to the fact that the probes were being used at moisture levels above their capabilities. The fact remained, however, that no other probes were known to be capable of coping with the situation.

To calibrate these probles, they were placed in wire mesh boxes filled with refuse and dunked in leachate until the refuse reached its maximum moisture-holding capabilities. The refuse-filled boxes were gradually dried and periodicaly weighed to calibrate the meter reading as a function of the percent moisture. Percent moisture was obtained as the ratio of the weight of water to the weight of refuse.

In analyzing the data the reader should be aware that the moisture values as given are felt to be representative of the moisture content range and not necessarily absolute values. There are several reasons for this. First, these probes read conductivity, and conductivity changes in the leachate could affect these readings. Second, the probes undoubtedly read moisture content at a point which may not reflect average moisture content levels. Finally, during calibration it was noticed that above a certain moisture level, the probes became insensitive. In the case of cell 4, for example, the probe readings were higher than could be obtained during calibration. Thus the probe readings were not valid above a certain percent moisture, and the straight line for the percent moisture plot resulted. In spite of the above difficulties, experience throughout the project indicates that the average readings from replicate probes calibrated in leachate are quite reliable up to the maximum probe reading, and are especially useful for tracing the movement of the moisture front through refuse.

Probe Installation

Temperature-moisture probes were installed at three depths - 6 in. from the bottom, mid-level, and 6 in. from the top of the refuse. Gas probes were installed at two depths - approximately a foot from the bottom and a foot from the top. A back hoe was used to dig a hole in the refuse to allow probe placement. Refuse was then hand compacted as the probes were installed at the various depths. The probes were installed at the cell center to minimize possible effects of the outside environment on data obtained.

During the week of cell construction an analysis of Madison refuse on a wet-weight basis was conducted by separating a total of one ton of refuse from the packer trucks as they dumped at the milling site to see if the refuse was characteristic of solid waste as produced in other municipalities. The analysis on a wet-weight basis is given in Appendix N.

PRELIMINARY DISCUSSION - THE DEGRADATION PROCESS

The rate and extent of degradation, and the removal of organic matter from a landfill, are dependent on a variety of interrelated factors. The two basic mechanisms resulting in removal of matter are physical and chemical leaching and biological decomposition. Physical and chemical leaching is brought about by the flow of water through refuse by which matter is rinsed or dissolved out. Biological decomposition refers to the degradation of refuse to leachable matter or gas by biological activity. These two processes are dependent on the following:

1. Presence of water. Water brings about physical and chemical leaching by the absorption of matter and, in addition, is a prerequisite for biological activity.

2. Temperature. Both ambient or outdoor temperature, and refuse temperature, affect the rate of decomposition. The greater the temperature within the refuse, the more quickly biological activity proceeds. The ambient temperature is important as it modifies the refuse temperature.

3. The presence of air. In the presence of air, aerobic decomposition takes place, which may be characterized by rapid activity producing sufficient heat to raise the temperature perhaps 30 to 40° F. above ambient within the refuse. If the rate of oxygen use exceeds the rate of replenishment, the refuse becomes anaerobic and a new set of organisms predominates. At first organisms which can tolerate the presence of some oxygen become important; these organisms characteristically produce partial decomposition of the organic matter. In so doing, partially decomposed organics are made available to the leachate, resulting in high COD levels. Since some of these organics are acidic, the pH drops. This process is called first-stage anaerobic decomposition.

As decomposition proceeds further and all oxygen is depleted, the methane-forming bacteria predominate. These organisms are able to decompose organic matter more completely to CH_4, CO_2, and H_2O. At this point the COD of the leachate decreases, the pH rises, and CH_4 is actively produced. This is called second-stage anaerobic decomposition and is associated with little or no heat release or temperature rise.

4. The effect of milling and mixing. Milling is thought to enhance the rate of physical and chemical leaching and biological decomposition by

increasing the surface area of the refuse, exposing more of it to biological and leaching activity, and by avoiding pockets of relative inactivity through mixing. Also, water flows more evenly through the entire volume of milled refuse, rather than channeling through and contacting only portions of the refuse which is not milled. Finally, by breaking up large items as cabbage heads, telephone books, etc., the refuse can decompose more uniformly, so that more of the readily removable matter is withdrawn from all of the refuse quickly, leaving a relatively inert mass behind.

Discussion of Data Obtained from Leachate Analysis:

To aid the reader in interpreting the graphs and figures, the following code will be used. A blank space indicates that there could have been a point at some level within the gap but none was obtained due to human error or equipment malfunction. The dashed line normally indicates an actual sampling attempt, but no sample was obtained (e.g. no leachate present).

The Water Budget:

Precipitation incident on a ground surface is removed by three basic means. It can evaporate; it can move along the ground surface as runoff; or it can infiltrate the ground surface and percolate downward. Landfill sites divide incident precipitation in the same manner, except the percolating water becomes known as leachate. One of the objectives of this project was to develop a water budget - i.e., to learn what part of precipitation becomes leachate, runoff, or evaporation for each of the various cells. Measuring leachate production, runoff, and precipitation are relatively easy; however, evaporation is extremely difficult to measure. For this reason, then, the determination of a water budget for the various cells involved obtaining the percentage of evaporation by subtracting the other two parameters from the incident precipitation.

Leachate Production:

Figure 66 indicates the amount of leachate pumped from each test lysimeter monthly throughout the test period, while Figures 3A and 3B provide moisture probe readings within each lysimeter, at three depths. Each reading is an average of values obtained from three replicate probes (certain probes were not included in these averages because of obvious inconsistencies).

General Observations

Field Capacity

Precipitation which infiltrates into the surface of the refuse cell moves downward into the cell and leaves at the bottom as leachate. In order to move downward in the absence of channgeling, the percolating water must thoroughly moisten each succeeding layer much like water spreading in a blotter. In a refuse cell, liquid can spread down only as long as there is enough moisture to keep the upper layers thoroughly soaked. When a layer has reached the point where it can no longer hold any more water

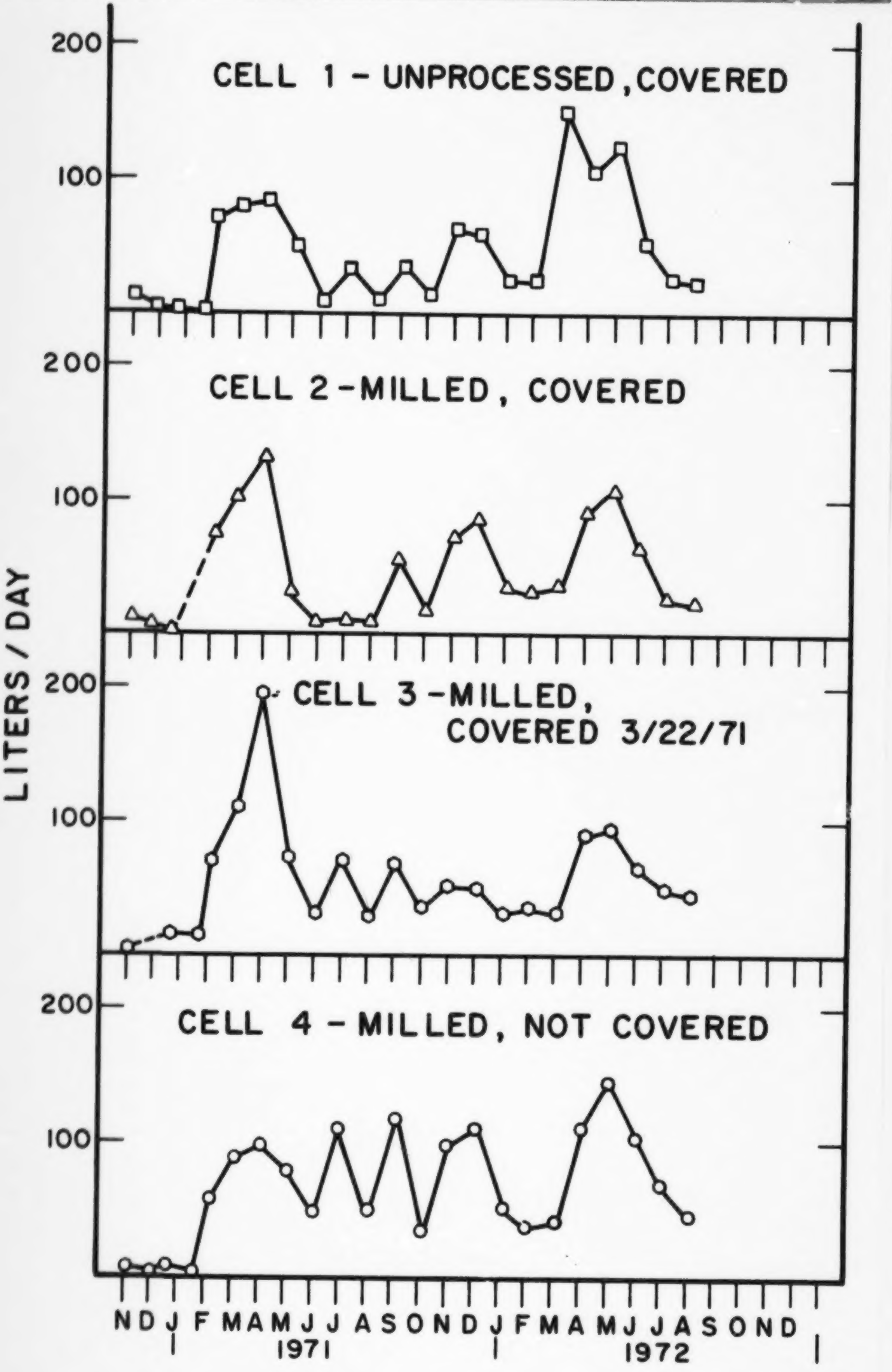


Figure 66. Volume of Leachate Production From Lysimeters

but must pass along as much water as enters, the layer has reached field capacity.

Of course channeling can occur in the refuse cells whereby some percolating water bypasses layers on its downward path, but this amount is small compared to the amount of leachate produced when the cell reaches field capacity. It is thought that with unprocessed refuse the opportunities for channeling are much greater than with milled refuse because of the more homogeneous character and degree of mixing obtained by milling.

Before a refuse cell reaches field capacity, leachate production should be minor and intermittant. By observing the plotted graphs of leachate production (**Figure 66**), just such a result can be seen. In all cases early leachate production is quite low when compared to later production, and with cells 2 and 3 no leachate was produced during one sampling interval.

As the cell layers approach field capacity the moisture curves should rise to a maximum point and level off barring long periods of drought or intense rainfall. The further down into the refuse the moisture content is monitored, the more constant will be the moisture content of a layer of refuse. This effect is generally observed in **Figures 67 & 68**, and especially in **Figure 68**. With all the cells at least some of the probes showed a rise to a plateau just before, or shortly after, steady leachate production began. With other probes (especially cell 1 and 2) the moisture levels were already at this plateau.

Due to heavy rain during the week of filling the cells, the refuse in all cells was exposed to soaking. Cells 1 and 2 in particular, constructed at the beginning of the week, received considerable precipitation. Though the cells were covered by tarps overnight, the refuse absorbed moisture during filling and also to some extent as it sat at curbside before collection. Consequently these two cells should have had initially higher moisture contents, which can be seen in the moisture curves. It is interesting to note that slightly higher leachate volumes were collected from cells 1 and 2 during the first two collection periods, again indicating a higher initial moisture content. In any case a rise in moisture content precedes the attainment of field capacity, and this must occur before leachate is consistently produced from refuse cells.

Effect of Spring Thaw

Another interesting observation with all cells was a noticeable rise in leachate production during late winter and early spring, concurrent with the spring thaw. Higher and more consistent production occurred in spring both years. Also, the cells reached field capacity during the spring peak of the first year, indicating that snow melt aided the refuse in reaching field capacity.

Cell 1 - The Unprocessed Covered Cell

Besides those observations on leachate production discussed earlier,

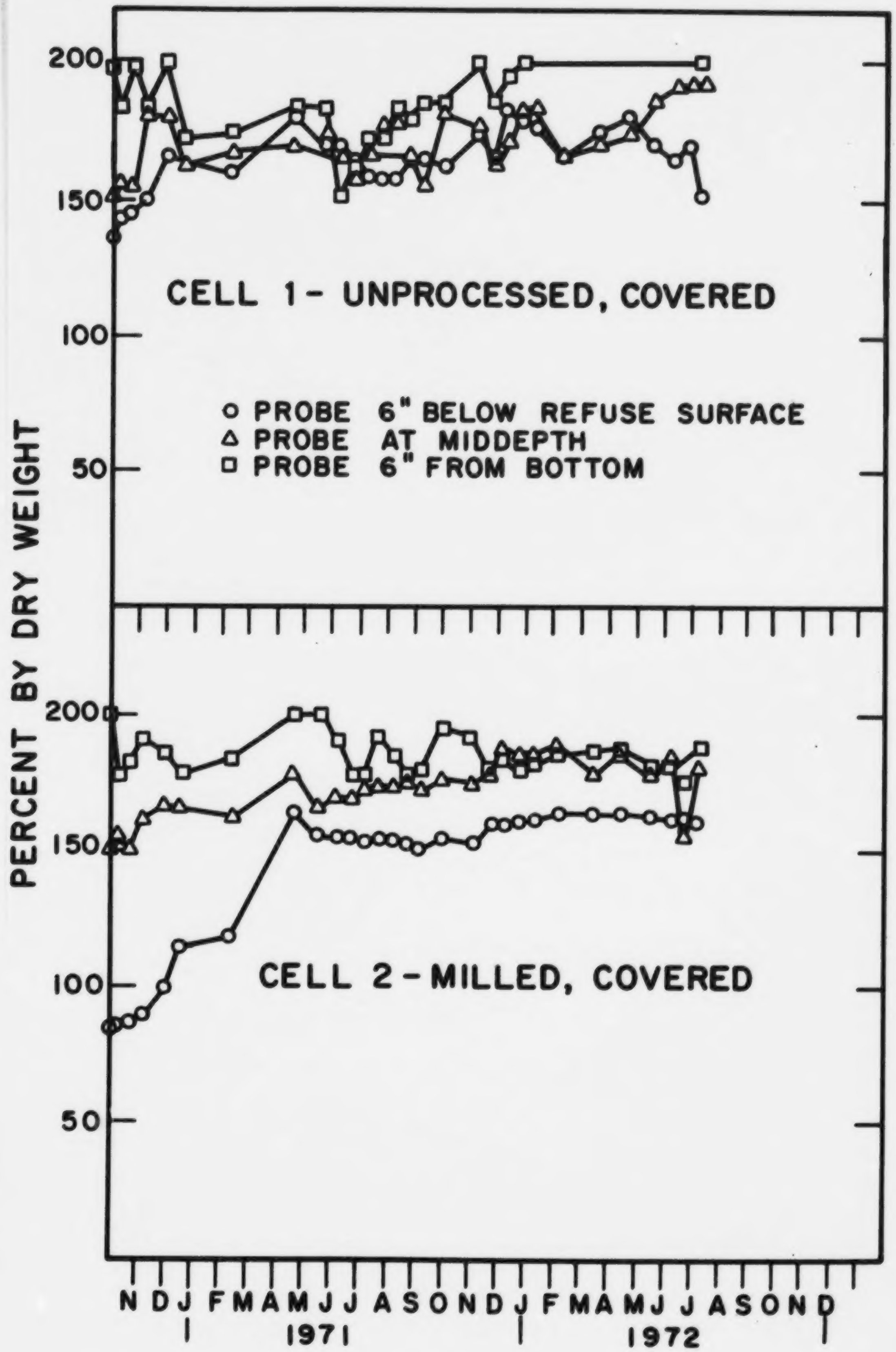


Figure 67. Refuse Moisture Content, Lysimeter Study (Cells 1 & 2)

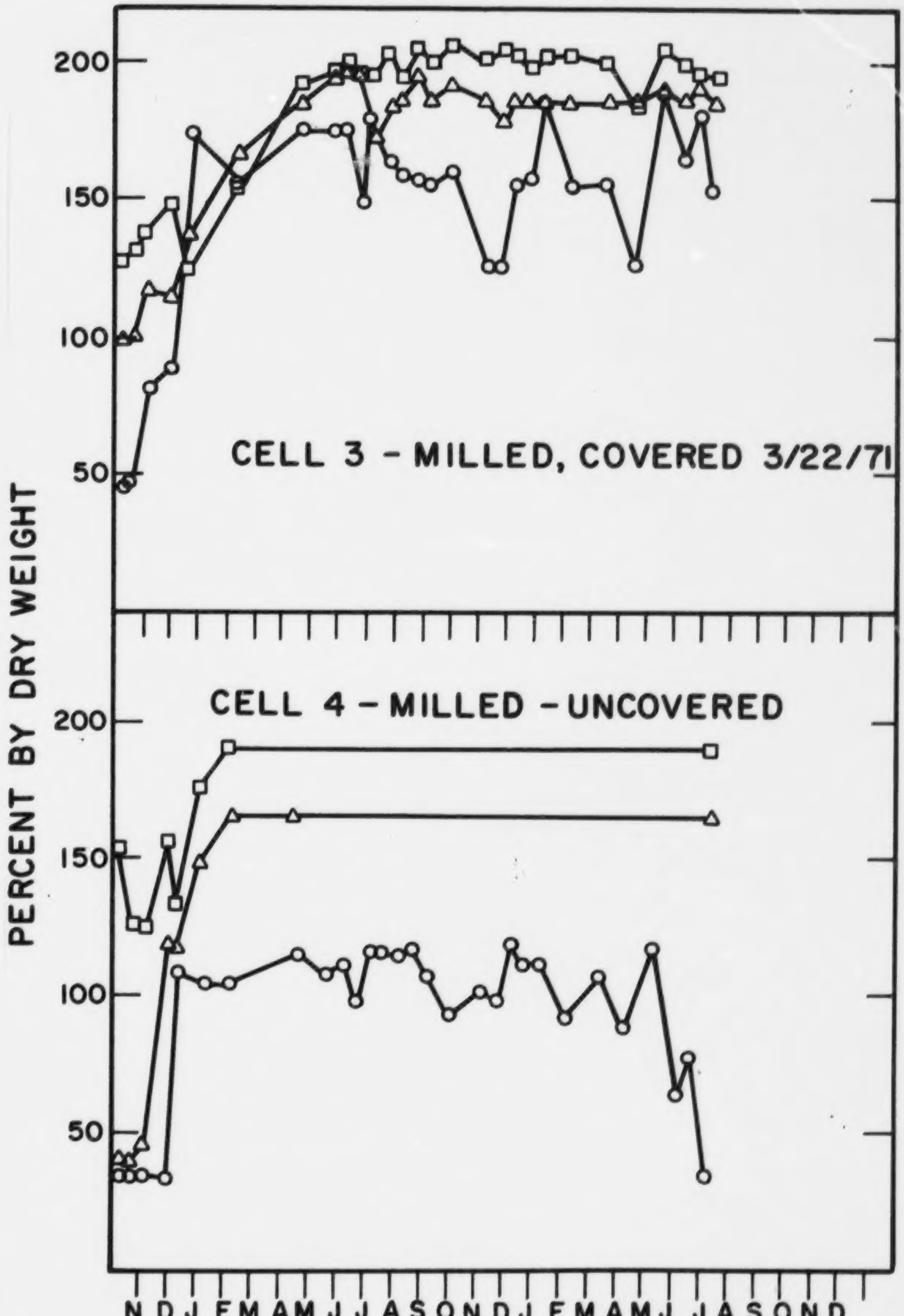


Figure 68. Refuse Moisture Content, Lysimeter Study (Cells 3 & 4)

cell 1 showed a significant dropoff from spring thaw production to a relatively low value during the summer months. Production rose again in late fall, indicative of effects from rains in September and October. Leachate production again dropped off over the mid-winter period due to lack of snow melt, only to pick up again with the onset of the spring thaw.

Cells 2, 3, and 4 - The Milled Cells

Since a primary objective of the project was to observe the effect of cover on milled refuse, these three cells will be discussed together. After reaching field capacity, cell 4, the milled cell with no soil cover, produced leachate at a rate higher than the unprocessed cell 1. Drastic fluctuations in leachate production from month to month were observed with this cell's leachate production, indicating that leachate production is highly dependent on incident rainfall with milled uncovered cells. Of course, extended periods of little precipitation or large amounts of precipitation tend to override these fluctuations, as is seen in the spring thaws and in mid-winter periods.

Cell 3 began producing leachate at a rate consistent with cell 4, as would be expected since initially they were both uncovered. However, in March 1971, 6 in. of soil cover were placed on this cell. Compaction of the cover on this cell resulted in squeezing out an abnormally large amount of leachate for the April 1971 sampling period. Production after this period commenced at a range much lower than that observed in cell 4. Of course some of this could be due to the soil cover absorbing water before reaching field capacity, but more importantly the soil serves to promote more runoff than the exposed milled refuse, which has a more spongy texture. With cell 3, then, leachate production becomes similar to that of cells 1 and 2, which were covered previously.

Cell 2, the milled cell covered with soil immediately, exhibited leachate production more closely following that of cell 1 from the start, with low production rates in the summer, a small peak for fall rains, and a higher peak for the spring thaw.

Figure 69, showing cumulative leachate production, more strikingly illustrates the effect of soil cover on the milled cells. The two cells covered immediately (1 and 2) closely follow each other throughout the sampling period. Cell 4 shows a faster rate of cumulative leachate production whereas cell 3 starts out quickly but slopes off to a rate of production similar to cells 1 and 2. This indicates that soil cover indeed has a direct bearing on leachate production.

The point at which the cells reached field capacity is very evident in this curve. It shows up as a sharp break in the curves during the February-March 1971 interval.

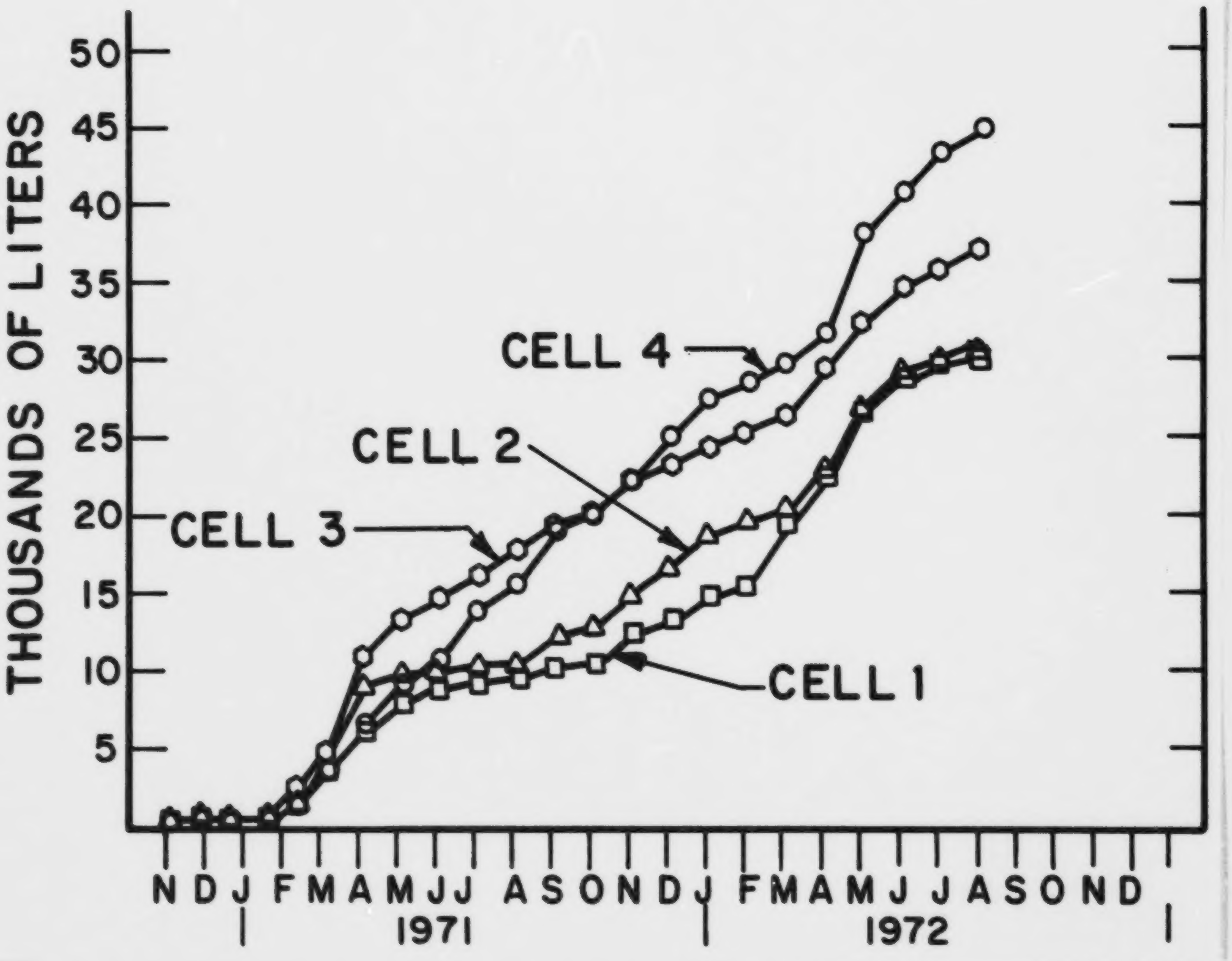


Figure 69. Cumulative Leachate Production From Lysimeter Cells

Chemical Oxygen Demand Concentration - Mg/L:

The chemical oxygen demand, or COD, is an indication of the amount of oxygen required to chemically oxidize the matter in water. As used in this report, it may be considered a measure of the concentration of organic substances present in leachate. COD concentration curves are given in **Figure 70.**

General Observations - Winter Peak of 1972

In January and February of 1972 a substantial rise in COD concentration occurred. This is especially noticeable in cell 2, and to a lesser extent in cells 1 and 3. Cell 4 had a negligible peak. At the same time in these cells the pH curves dropped, as did temperatures and percent methane (CH_4), if any methane was present in the cell at the time.

These incidents occurring at the same time suggest that the low temperatures within the cells might have restricted bacterial activity. With this occurrence refuse was not being degraded to as low an oxygen-demanding state as before - thus the rise in COD concentration and decrease in pH due to failure to reduce organic acids present. In cell 4, especially in the lower portion of the cell, the temperature was usually slightly higher, so possibly the bacteria were not retarded to as great an extent.

Cell 1 - The Unprocessed Covered Cell

The COD concentration curve (**Figure** 70) shows a slight initial rise, possibly indicating the release of some readily available organics which could easily be leached from the refuse cell. Winter produced a slight decline in concentration followed by a peak during the spring thaw. The spring thaw indicates that the large volume of water, along with a rise in temperature, aids biological and leaching activity, thus bringing about more substantial organic removal. The summer months see a steadily declining concentration of COD in the leachate. This suggests that organisms are either reducing the organic matter to a lower oxygen demanding state or that very little organic matter is being removed in relation to the amount of leachate passing through. Later in this report, when the gas results for this cell are presented, it will be observed that little or not methane is present at this time.

Again in the spring of 1972 the inordinately large amounts of water passing through the cell help remove large amounts of organic matter, some of which possibly may not have been leached out otherwise. Then, too, increased biological activity with the spring warmth helps break down matter so that it can be leached out even if the degradation process has not reached final stages.

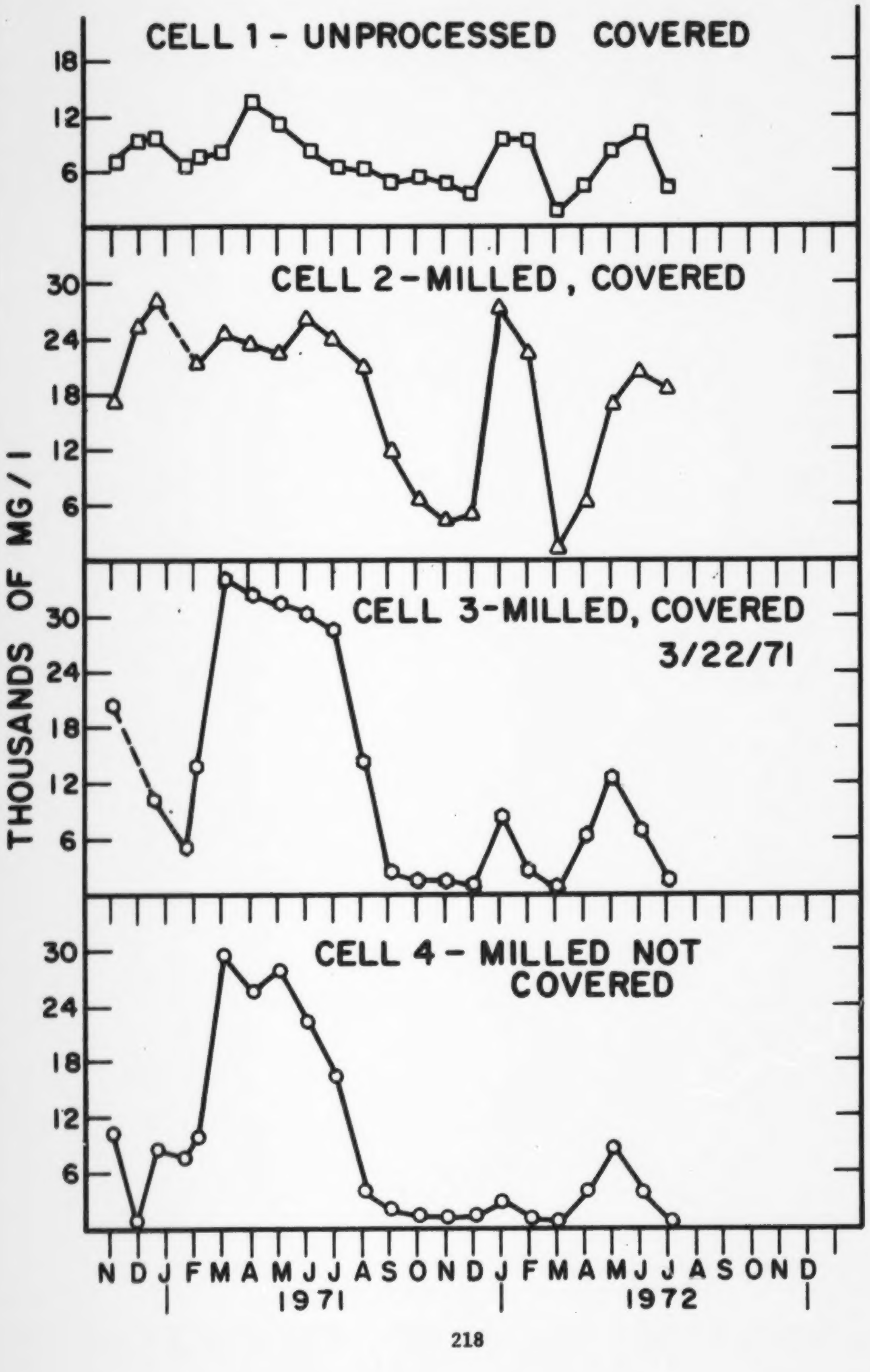


Figure 70. Leachate Chemical Oxygen Demand From Lysimeter Cells

Cells 2, 3, and 4 - The Milled Cells

Data from the Olin Avenue project indicated that the typical milled cell had a high initial peak COD followed by a rapid decline to relatively small values thereafter. A secondary peak usually occurred during the following summer. In the present study, cell 4, the milled cell left uncovered, shows just such a curve (**Figure 70**). The curve also shows a high initial COD value followed by a rapid dropoff prior to the rise to the peak value. This first high value may be due to squeezing out moisture already in the refuse by compactive effort, or to the lack of a mature biota to modify the leachate composition.

This same set of characteristics is observed with cell 3, except for the longer duration of the initial COD peak and the higher and longer secondary peak in the winter and summer of 1972. With cell 2 the initial COD peak is of longer duration than in cell 3, and the mid-winter 1972 peak is extremely high, even as high as the initial peak. Further the second summer peak (1972) is very pronounced and drawn out when compared with the secondary peaks of the other cells.

Since all three cells are composed of milled refuse, the only difference between the cells is the presence or lack of soil cover, and the timing of cover placement. Since the same amount of organics (refuse) are available for degradation and for leaching from each cell, this must indicate an influen-e of cover on the degradation process. Apparently, with cell 4 conditions are more conducive to biological degradation, followed in order by cells 3 and 2. To repeat, cell 2 was covered with soil immediately, cell 3 was covered six months after cell construction, and cell 4 was left uncovered.

Examining other parameters such as moisture and temperature (**Figures 68 and 69; 83 and 84**) the reader will notice that moisture conditions are essentially the same in all 3 cells, whereas cell temperatures are somewhat higher in cell 4 than in the other two cells. Cell 3 had temperatures much like cell 4 until it was covered with soil and then the temperatures dropped off. Leachate temperature (**Figure 85**), another indicator of biological activity, is higher with the uncovered cell 4 than with the other two. Essentially, then, soil cover seems to result in lower cell temperatures, retarding the degradation process and thereby releasing a more concentrated leachate to the surrounding environment. Extrapolating this assumption, one could surmise that soil cover also played a role in retarding the degradation process in the unprocessed covered cell, a possibility that is borne out by the data. Finally, it is noted that this effect may be due to several possible mechanisms, but one which seems particularly reasonable in light of all of the decomposition results reported in this work is the stabilization or treatment of leachate as it passes through a mature refuse mass, under conditions conducive to biological, and possible ehcmical, activity. The general shape of the COD concentration curve for a milled uncovered cell, and the effect of dousing cell 2 in the Olin Avenue field degradation studies, are especially interesting in this regard.

Chemical Oxygen Demand Production - Grams/Day:

It is obvious that the concentration of COD is not in itself of great importance in its effect on the environment for a small amount of leachate produced at a high COD concentration should be no worse than a large volume of leachate at a much lower COD concentration. For this reason it is logical to calculate the actual amounts of chemical oxygen demanding substances produced from a cell. To obtain this value the COD concentration is multiplied by the average volume of leachate produced per day between samplings to yield the grams of COD produced per day (**Figure 71**).

General Observations

All cells initially showed very little total COD production since little leachate was produced until cells reached field capacity. With the spring thaw and attainment of field capacity, substantial COD production began, with faster production in the milled cells than in the unprocessed cell.

Cell 1 - The Unprocessed Covered Cell

Generally the COD production curve follows the COD concentration curve with the exception that it is much smoother with no drastic fluctuations. There are three peaks in the curve: two at spring thaws and one at mid-summer. These, of course, come at times of high COD concentration or leachate production or a combination of both. At other periods the COD production occurs at a fairly constant pace.

Cells 2, 3, and 4 - The Milled Cells

In all cases the milled cells show a rise to a peak very quickly after the cells reach field capacity. From that point the production curves diverge. Both cells 3 and 4 show broader initial peak envelopes indicating that COD-producing organics are being removed from the cells quite rapidly. It is interesting that even after cover was placed on cell 3, these two curves did not diverge significantly. These two curves are more closely related than any other two curves on the figure. Cell 2, on the other hand, did not produce as many grams of COD per day in its initial peak, but later on COD production rates were higher than any of the other cells. It should be noted here that compaction of soil cover on cell 3 undoubtedly squeezed out more grams of COD than would be expected if the cell were left alone.

Additional Discussion of COD Production Curves

The COD production curves indicate that the initial peak envelopes of cells 3 and 4, which were then both uncovered, were of longer duration than cell 2, but that later on the soil-covered cells produced more grams of COD per day. These phenomena can be explained by the nature of milled refuse and the effect of soil cover. As explained previously, milling refuse exposes more refuse surface area and, of course, produces finer particles.

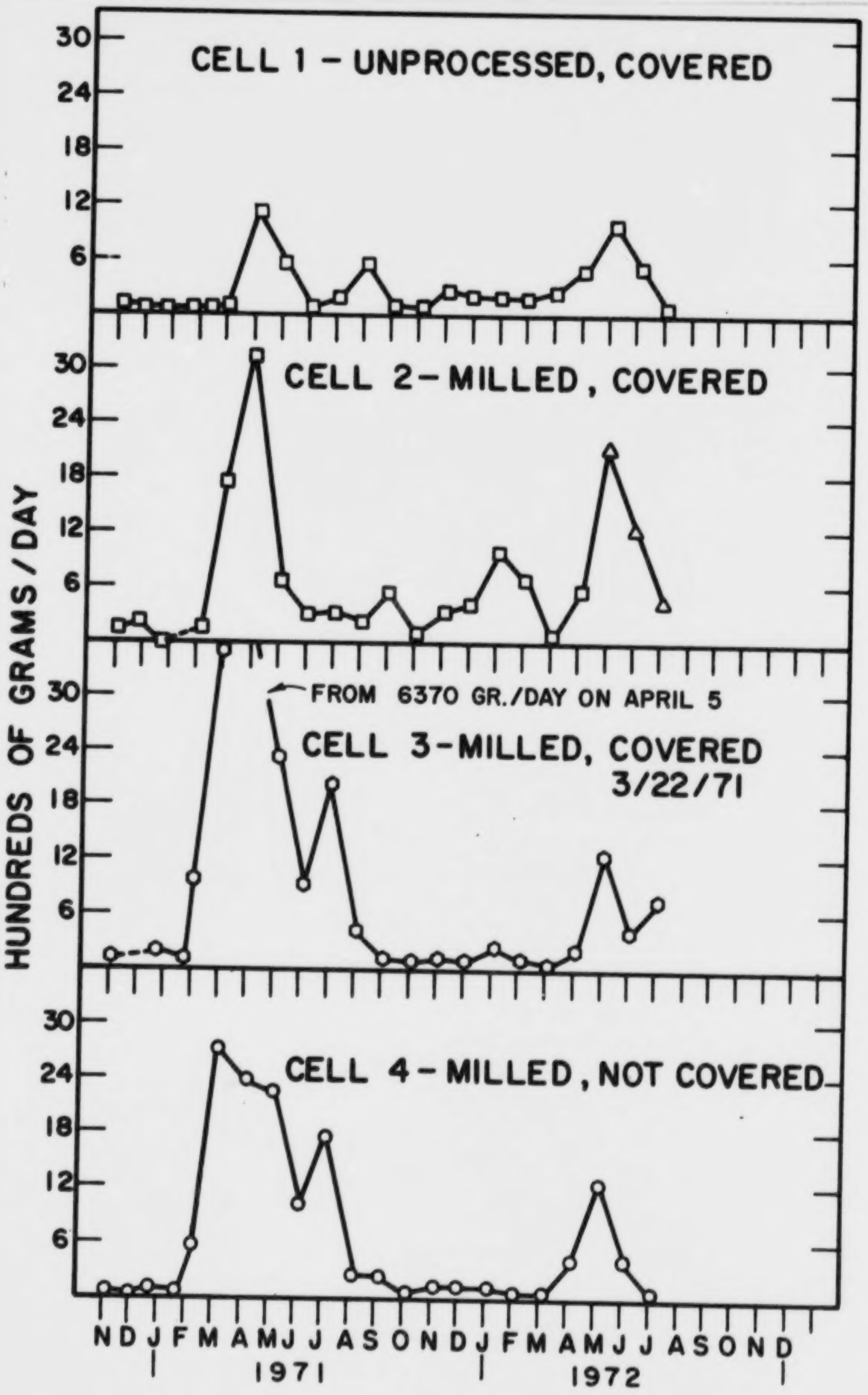


Figure 71. Chemical Oxygen Demand Production, Lysimeter Study

Soil cover **tends** to result in lower cell temperatures, aids runoff, and retards infiltration of water into the cells.

This produces the following results. In the cells without cover more precipitation becomes leachate which removes initially more organic matter from the cell. Thus, more grams of COD per day are produced in the milled cells without cover than in the milled cell covered with soil. At the same time this increased amount of leachate tends to lower the COD concentration.

As time goes on the greater amount of leachate in the uncovered milled cell has less effect in grams of COD produced. The reason why this occurs may be that first, the more readily degradable matter had been removed more quickly and uniformly from the milled refuse. Second, a mature biota brings about more complete degradation as evidenced by methane production in the cells (**Figures 87 & 88**). This may be termed second stage anaerobic degradation in which organics are degraded to a low oxygen-demanding state. This will be discussed in more detail later. Third, the initial large amount of leachate may have washed out organic matter which may have stayed in the cell under lesser leachate flow rates.

With the unprocessed cell 1, the organic matter particle size is, of course, much larger and the organic matter is not as well mixed as in the milled cells. Because this cell and cell 2 were both covered immediately, leachate production is on the same order as cell 2. The result is that less organic matter has a chance to be leached initially out of this cell when compared with the others. With the smaller surface area of refuse exposed in the unprocessed cell, degradation proceeds at a slower rate than in the milled cells, and further, the soil cover slows the rate of infiltration.

A plot of cumulative COD production will possibly simplify the above explanation (**Figure** 72). All three milled cells produced more cumulative grams of COD than the unprocessed cell. The effect of soil cover on the milled cells is to decrease the amount of infiltration which temporarily limits the production of COD, but cover also prolongs active degradation as evidenced by the greater slope on the cell 2 curve than the cell 4 curve. It is difficult to make any conclusions from the cell 3 COD production curve. There is the rapid rise in the curve which is more pronounced with this cell because of the placing of soil cover. However, the long-term effect of this soil cover was probably seen only in the last months of recorded data. It evidently took that long for the cell to recover from the placement of cover and become stable. According to the other results, it might be predicted that the slope of the production curve will begin to rise as degradation continues later in the decomposition sequence.

With cell 1, the unprocessed covered cell, there is a smaller rise until field capacity is reached, again indicating the smaller amount of organics readily available for physical leaching. After this the rate of production proceeds at a rate somewhat lower than cell 2 but greater than the milled uncovered cell 4. This suggests that the

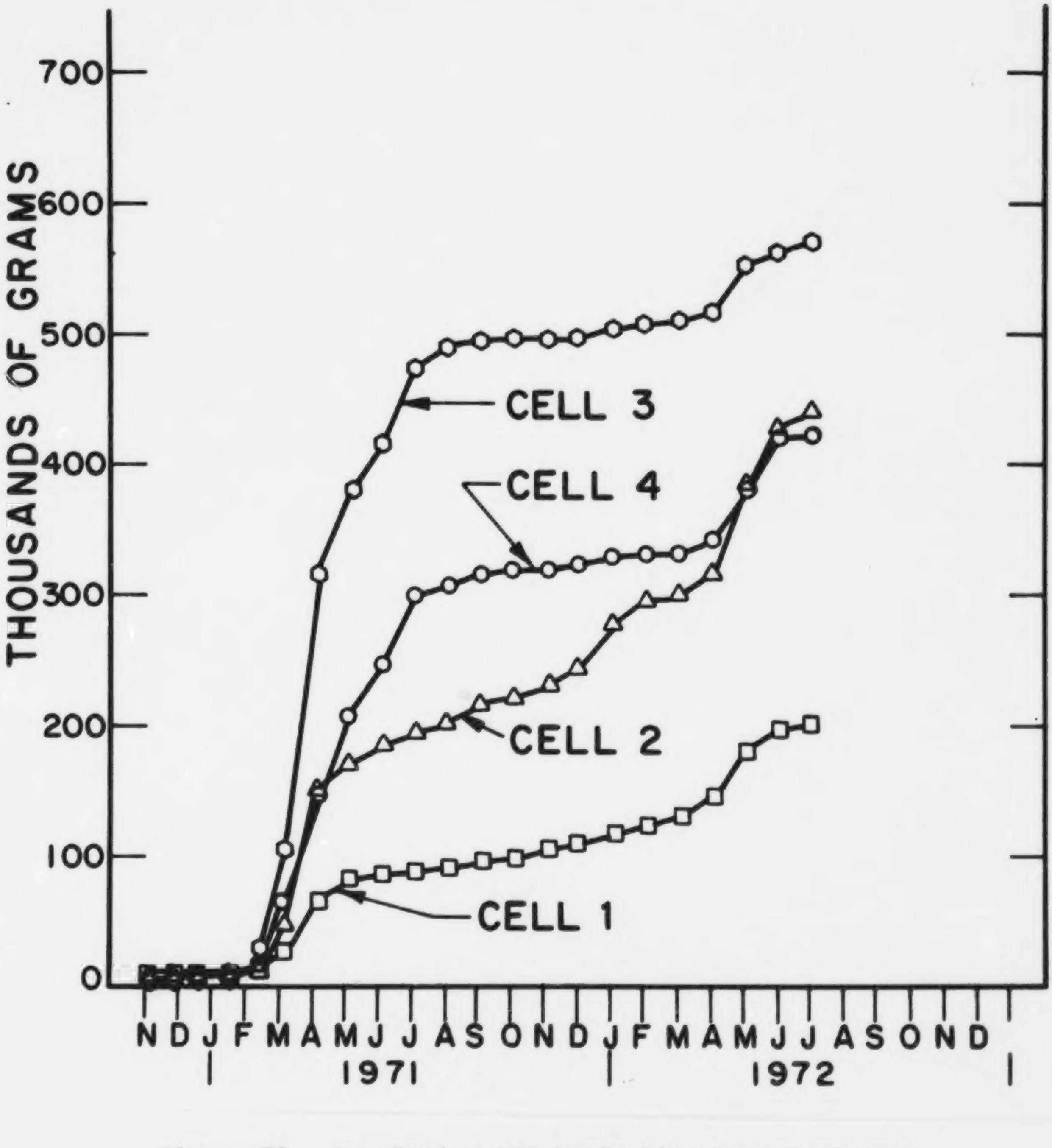


Figure 72. Cumulative COD Production From Lysimeter Test Cells

curves for these two cells may cross at a future time. Also evident is the fact that spring thaw, with its higher attendant leachate flow, does not produce COD as rapidly with cell 1.

Conductivity:

Conductivity, or more correctly specific conductance, is a measure of the total concentration of dissolved matter (largely inorganic ions) present in the leachate. Together with COD values, conductivity indicates the total gross concentration of pollutants in leachate. The conductivity data are presented in Figure 73.

General Observations

The shapes of the conductivity curves somewhat resemble those of the respective COD concentration curves to the extent that, as organic matter is being directly leached or dissolved and removed by the leachate, so to is inorganic matter. Biological activity can affect conductivity indirectly by changing pH and temperature but the effect is not so great as with organic matter. This simply means that when organic concentrations are reduced to lower values by biological activity, conductivity values are not necessarily reduced proportionately.

Cell 1 - The Unprocessed Covered Cell

The conductivity curve for the unprocessed cell fluctuates over a fairly narrow range as compared to the other three curves. The curve follows quite closely the shape of the COD concentration curve, a characteristic noted in the Olin Avenue studies.

Cells 2, 3, and 4 - The Milled Cells

With the milled cells again, the conductivity curves resemble in shape the COD concentration curves, with cell 2 showing the most similarity and cell 4 the least. Evidently soil cover has some bearing on this. Possibly with the attendant increased solubilization of inorganic matter. Then, too, with limited COD concentration values late in the degradation process for cell 4, the pick-up by leachate of inorganic matter, which is relatively unaffected by this degradation, would still be produced in quantity. With the covered cell 2, where less rapid degradation of organics is taking place due to a less satisfactory environment for biological activity, the later COD concentration values are higher and fluctuate with seasonal temperature changes, incident precipitation, etc. With the more uniform degradation and/or release of the organics comes the gradual release of some inorganics, and the fluctuations of the COD concentration curve become more similar to those of the conductivity curve. Note that this discussion concerning cell 2 is also applicable to cell 1.

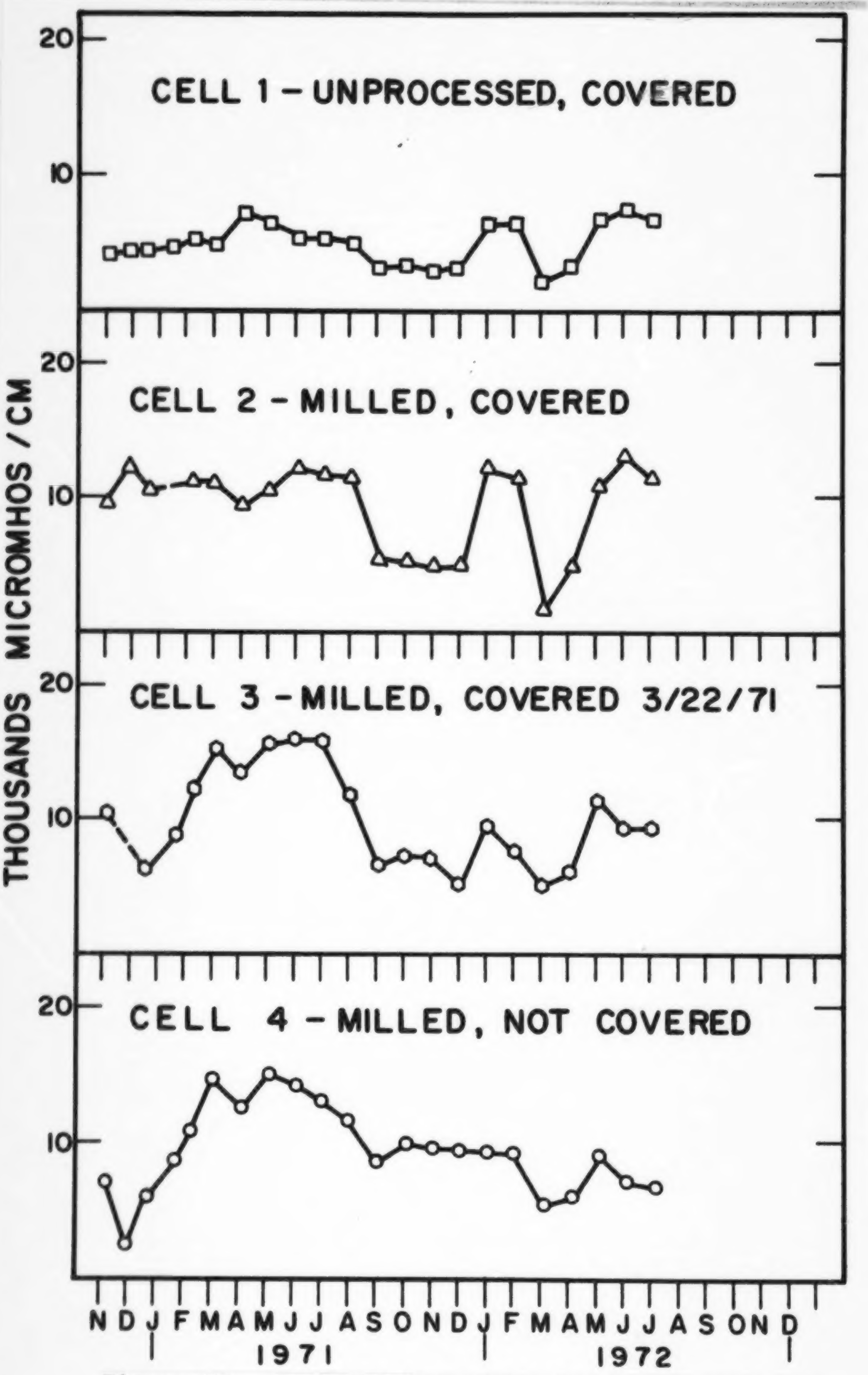


Figure 73. Conductivity of Leachate From Lysimeter Test Cells

The Specific Ions:

Conductivity is a measure of the ability of a liquid solution to carry an electric current, which is in turn related to the number and type of ions contained in the solution. Because of this close relationship, the curves of these specific ions should resemble the conductivity curve. Analyses run for this study which measure the presence of these ions are alkalinity, total and calcium hardness, chloride, iron, and to a limited extent nitrogen, and phosphorus. These curves are shown primarily for interest to document the magnitudes and changes in magnitudes of these specific ions.

Alkalinity

The alkalinity of water is a measure of the capacity to neutralize acids and is due primarily to salts of weak acids such as carbonates and phosphates. Carbonates, of course, can be formed in the degradation process. The production of CO_2 during biological degradation can give rise to alkalinity in leachate directly depending on the degree of basisity of the refuse and the leachate.

In observing the alkalinity curves of **Figure 74, it is apparent that the** shapes of the curves do closely follow the respective conductivity curves. Thus the discussion concerning conductivity will also apply here.

Total and Calcium Hardness

Hardness is caused by the presence of divalent metallic cations, where calcium, magnesium, and iron are the principal ones. Calcium hardness is, of course, a measure of the calcium cation, a component of total hardness. Hardness is a significant component of leachate in that in large quantities it can limit the usefulness of groundwater. It is of special interest because it is one of the components of leachate which has been shown to travel reasonable distances through soils to degrade groundwater. Total and calcium hardness curves (**Figures 75 & 76**) resemble their respective conductivity curves.

Chlorides

Chlorides are of significance in a study of refuse decomposition because of their relative inability to be degraded or sorbed in passing through refuse or soils. In fact, they are often used as tracers in groundwater studies because of their inertness. In sanitary landfills, therefore, they can be used to indicate the extent to which the landfill affects surrounding groundwater, if base levels are known. Further, because of their inertness any chlorides arising from a landfill will likely join eventually ground or surface waters, possibly influencing the quality of such waters. The chloride curves, **Figure 77**, follow closely the shapes of the conductivity curves.

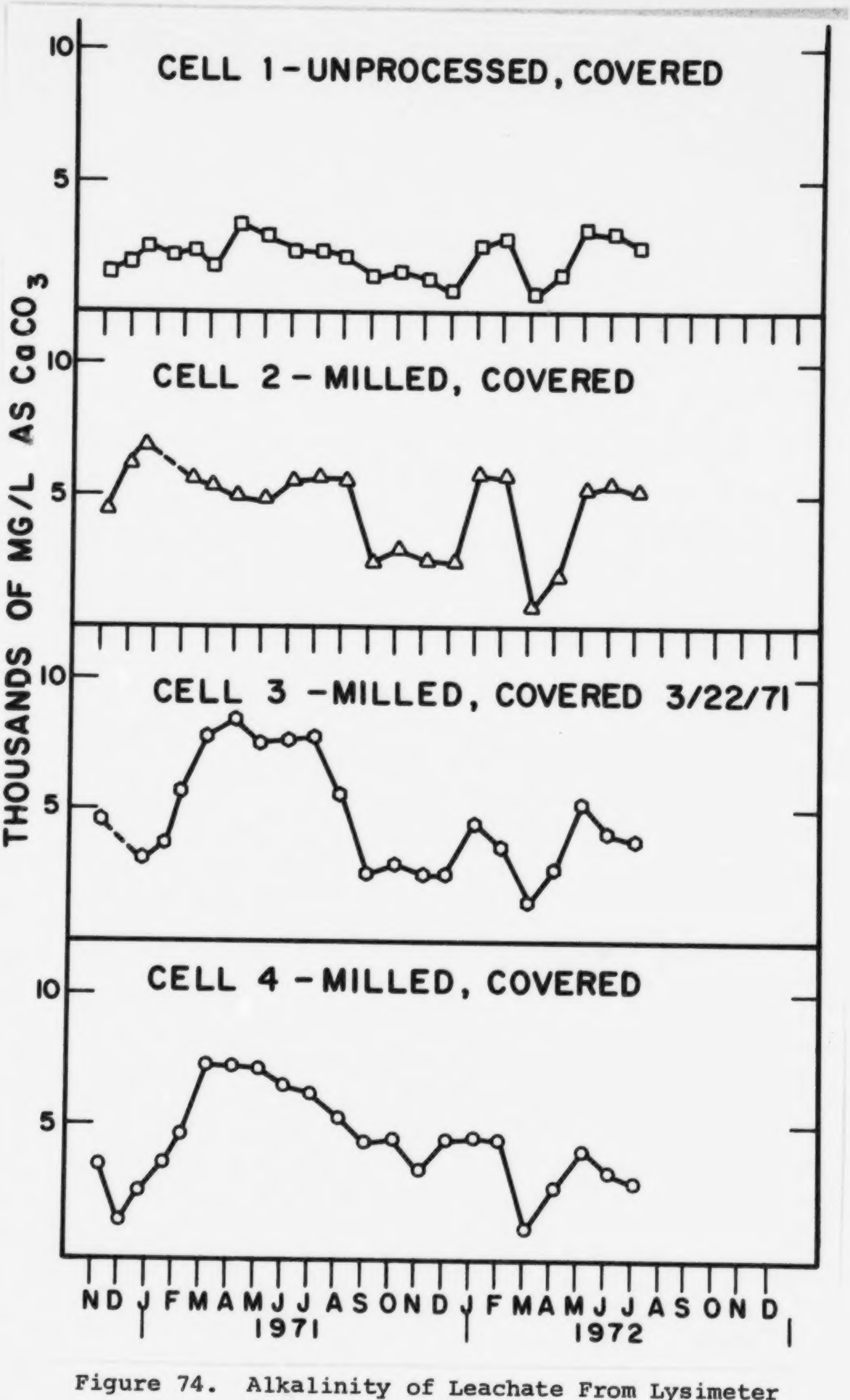


Figure 74. Alkalinity of Leachate From Lysimeter Test Cells

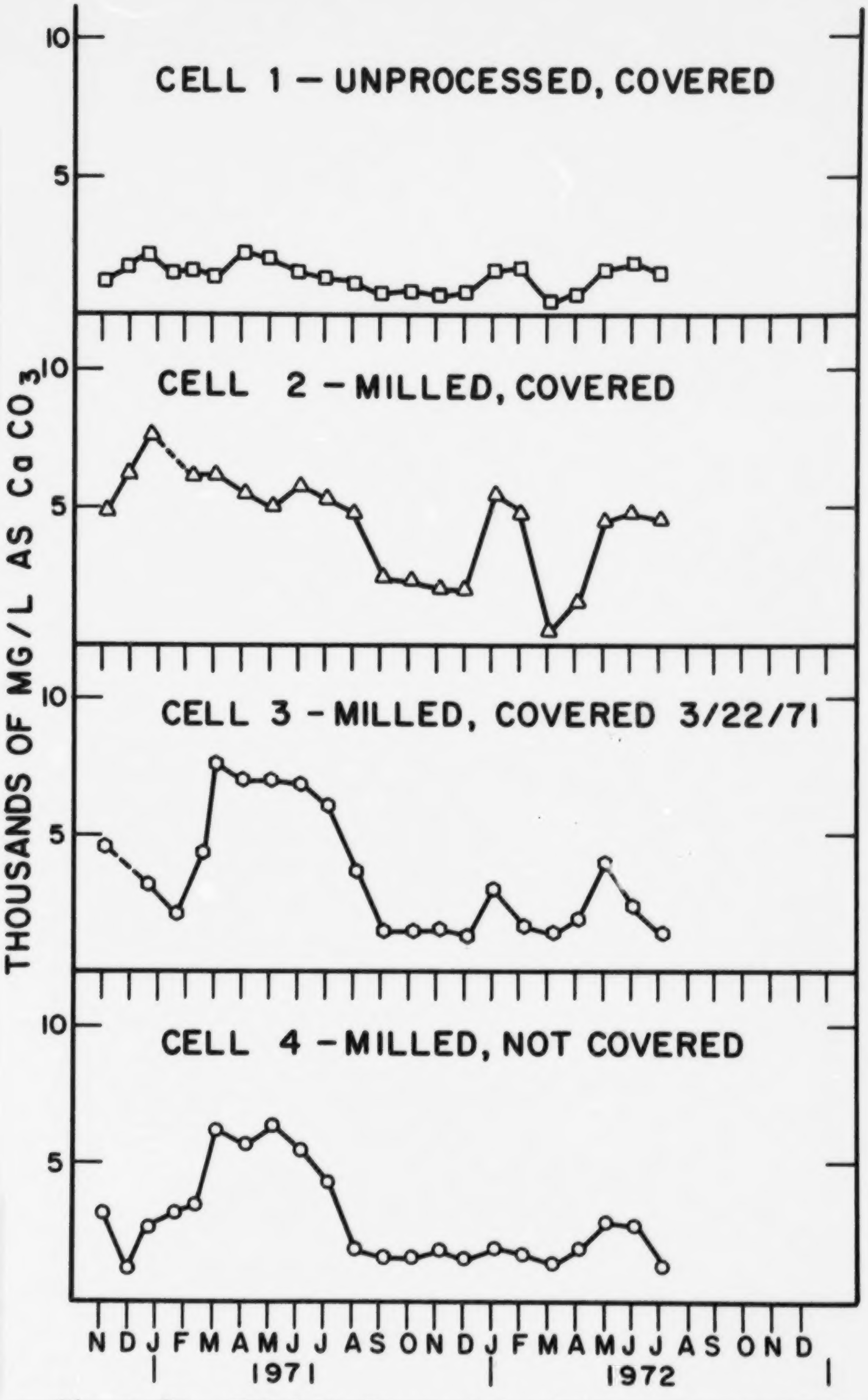


Figure 75. Total Hardness of Leachate From Lysimeter Test Cells

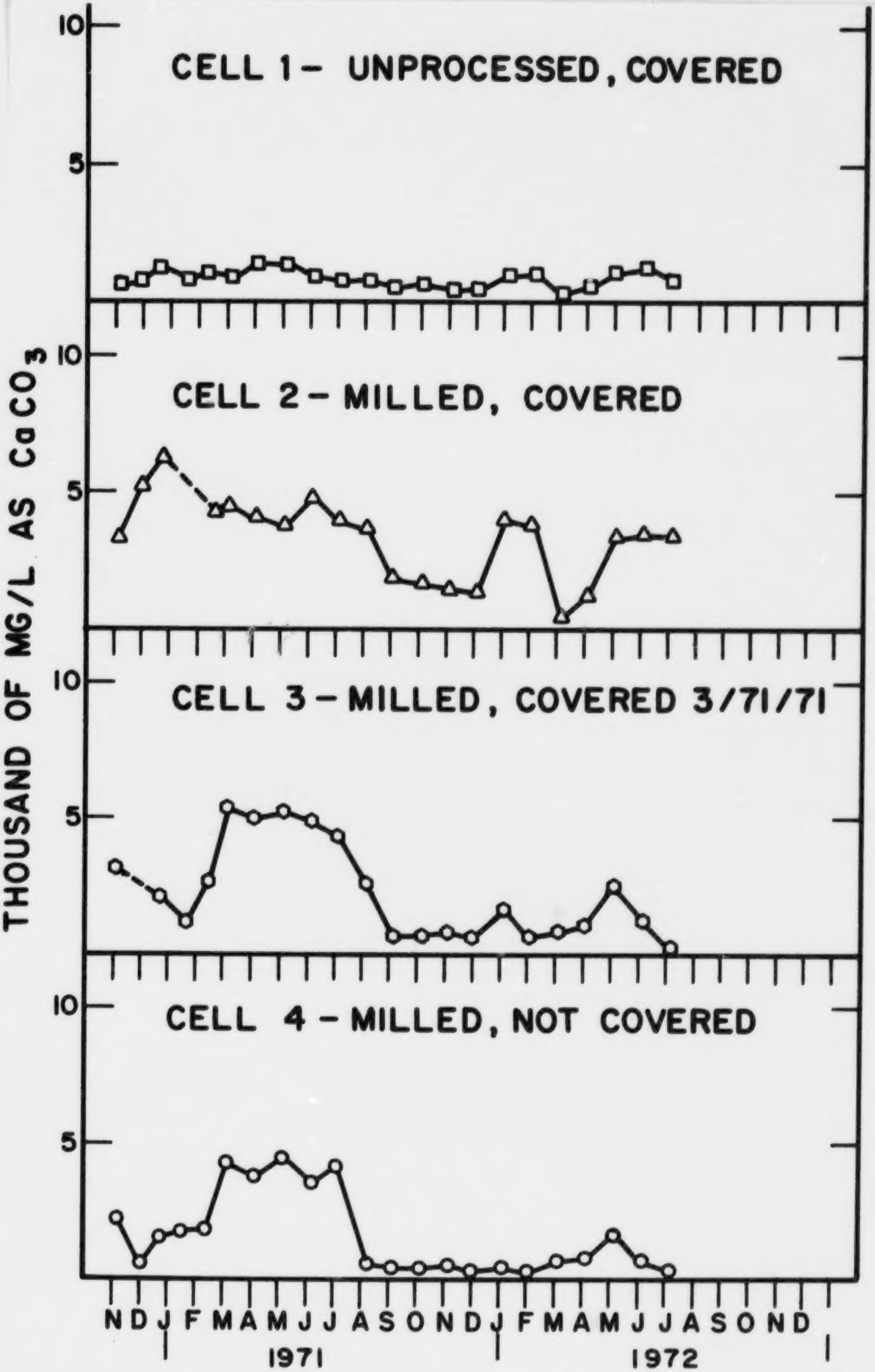


Figure 76. Calcium Hardness of Leachate From Lysimeter Test Cells

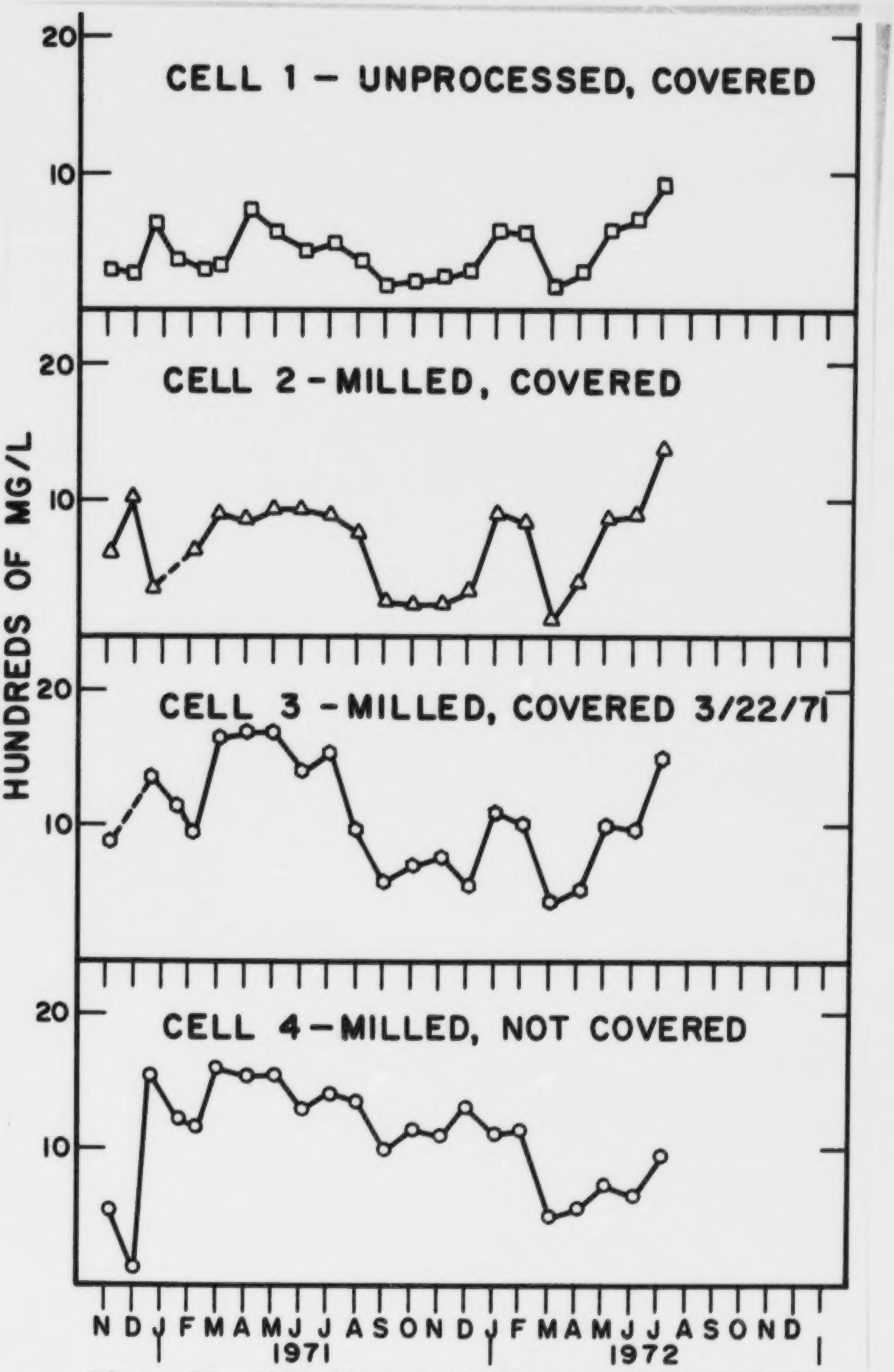


Figure 77. Chloride Concentration of Leachate From Lysimeter Test Cells

Iron

The iron results are presented in **Figure 78.** The curves are again seen to follow the general shape of the respective conductivity curves. The iron curve of cell 4 is somewhat different in shape in that it drops off faster, much like the total hardness curve, of which it (iron) is a component.

Iron is of special significance because it is frequently found in groundwater and so is one component in leachate which would seem to have the ability to pass through soils, much like chlorides, without major degrees of attenuation. Further, the PHS drinking water standard limit for iron is sufficiently low (0.3) ppm) that it may be of significance in some localities.

Note that the iron content of leachate from all of the milled cells is much higher than that from the unprocessed cell. This is thought to be due to the exposure of more iron to leachate in milled refuse by virtue of paper and paint removel from cans, etc.

Nitrogen Analysis

Two types of nitrogen were studied extensively (**Figure 79**)-organic nitrogen and ammonium nitrogen. On several occasions nitrate-nitrite was determined but with only few samples, no significant data were obtained but is indicated for information purposes only (Table 50). Ammonium nitrogen is the nitrogen that exists as the ammonium ion, while organic nitrogen is the nitrogen present as organic compounds. The presence of organic nitrogen usually means that amino acids and polypeptides are present, both of which are products of the degradation of proteins.

Table 50

Nitrate-Nitrite Nitrogen Analysis (Mg/L)

	Cell No.			
Date	1	2	3	4
May 3, 1971	31	22	55	60
June, 1971	8	12	30	22
July 8, 1971	0	0	12	13
Sept, 1, 1972	3,7	0	0.3	0

The data are shown in **Figure 79.** The ammonium nitrogen follows fairly closely the conductivity curves, as do the shapes of the organic nitrogen curves. Organic nitrogen in large quantities indicates that active degradation is taking place. In small quantities it indicates that either the matter undergoing degradation is stabilizing or that little degradation is

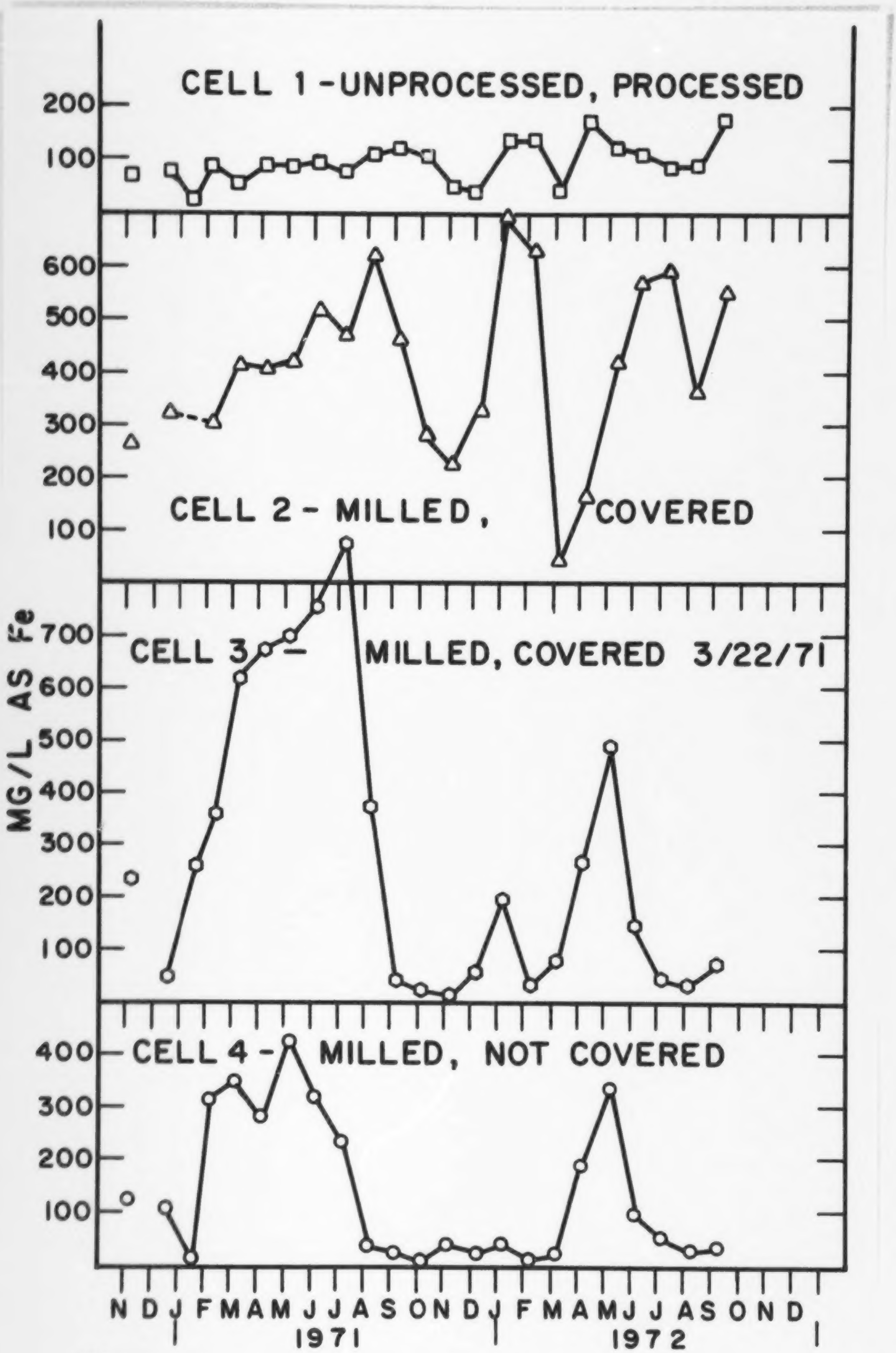


Figure 78. Iron Concentration in Leachate From Lysimeter Test Cells

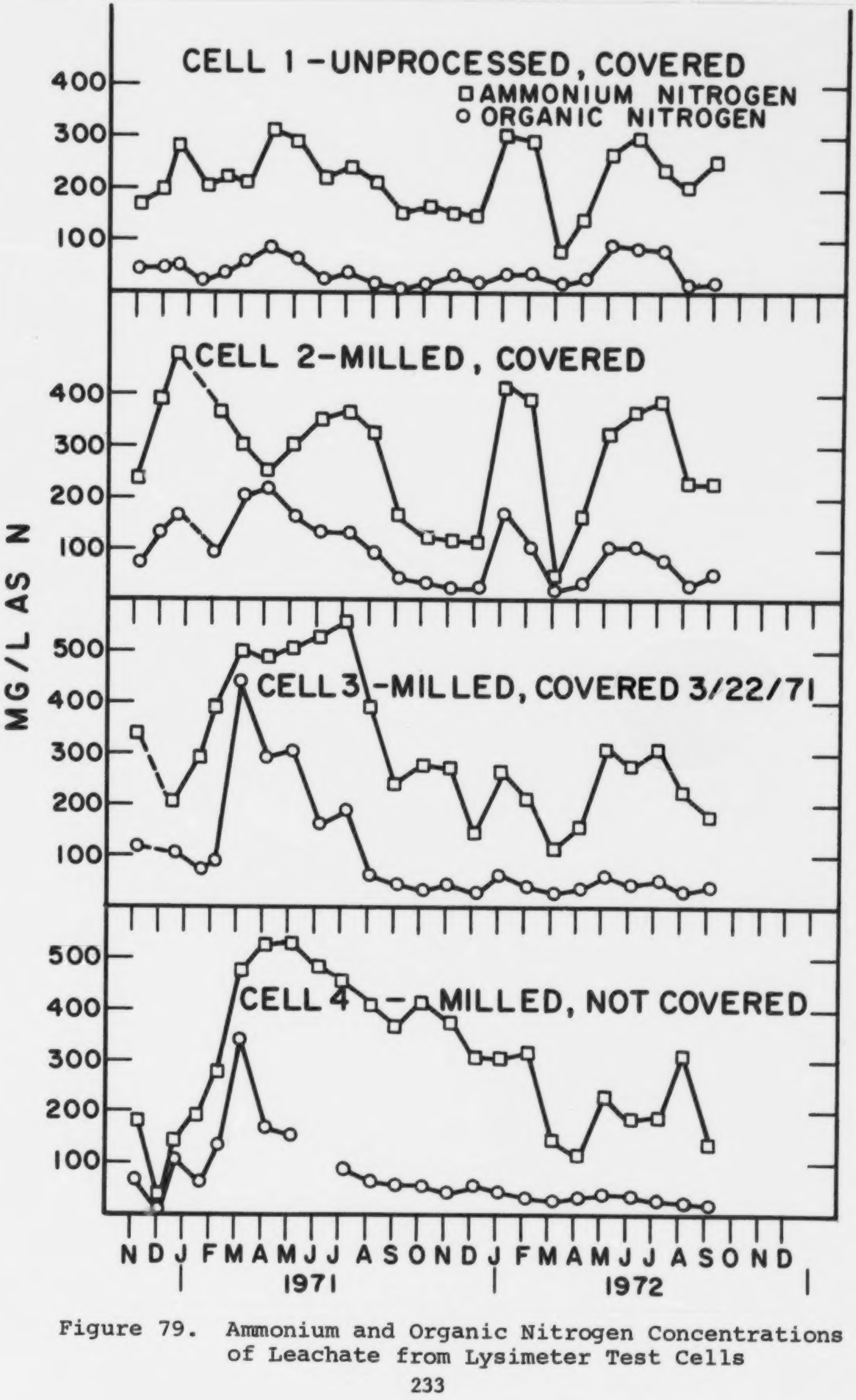


Figure 79. Ammonium and Organic Nitrogen Concentrations of Leachate from Lysimeter Test Cells

taking place. With cells 1 and 2 degradation seems to have occurred at a relatively constant rate, since organic nitrogen occurs at a fairly constant level. This likely indicates that the degradation rate is less for these cells than cells 3 or 4 during their peak degradation period. Such a conclusion supports the other leachate results. With cells 3 and 4 the degradation seems to be stabilizing since production was at an initial high peak and has dropped consistently to a level approximately one-half of the peak value. It is likely that production of both ammonia and organic nitrogen is degradation-dependent, giving substance to the similarity of the shapes of the respective curves.

Phosphate Analysis

Three phosphate analyses were run: total phosphate, total soluble phosphate, and soluble orthophosphate. The latter was discontinued in December 1971 because of the similarity between it and total soluble phosphate. Total phosphate is defined as a measure of all forms of phosphorus present in the wastewater. Total soluble phosphate is that portion of total phosphate which passes through a 0.45 mm membrane filter as defined in Standard Methods. Soluble orthophosphate is that portion of total soluble phosphate composed of compounds of $H_2PO_4^-$, HPO_4^{-2} and PO_4^{-3}. The soluble phosphate and orthophosphate values are of interest because the forms may be expected to travel more readily through soils, if at all.

In general all phosphate curves **(Figures 80 and 81)** show a general downward trend. The milled cells show initially very high peaks followed by rapid drop offs. This indicates that phosphorus was rinsed from the cells or a mature biota was formed after the peak which was able to take up some of the phosphate and keep concentrations reduced after this point. Probably it is a combination of both. It is interesting to note that initial peaks are higher in the milled covered cell 2 than in the then-both-covered milled cells 3 and 4 possibly indicating that the establishment of this biota is not quite developed.

Cell 1 does not show the initial high peak, but later data show phosphate values somewhat higher with this cell than with the others. This may indicate that a mature biota has not been produced to reduce the phosphate levels.

pH:

The pH measurement **(Figure 82)** is of interest in analyzing data from refuse cells not only because it is an important characteristic of the leachate composition, but because it can be used as an indication of what type of degradation process is occurring and what degradation products are forming. The discussion on degradation in the COD section points out that once mature anaerobic degradation occurs, the pH should rise to near neutral levels. Acidic pH levels are not considered optimal if degradation is to be promoted, because of adverse effects on many microorganisms. Acid pH values are obtained during the transition period between aerobic and strictly

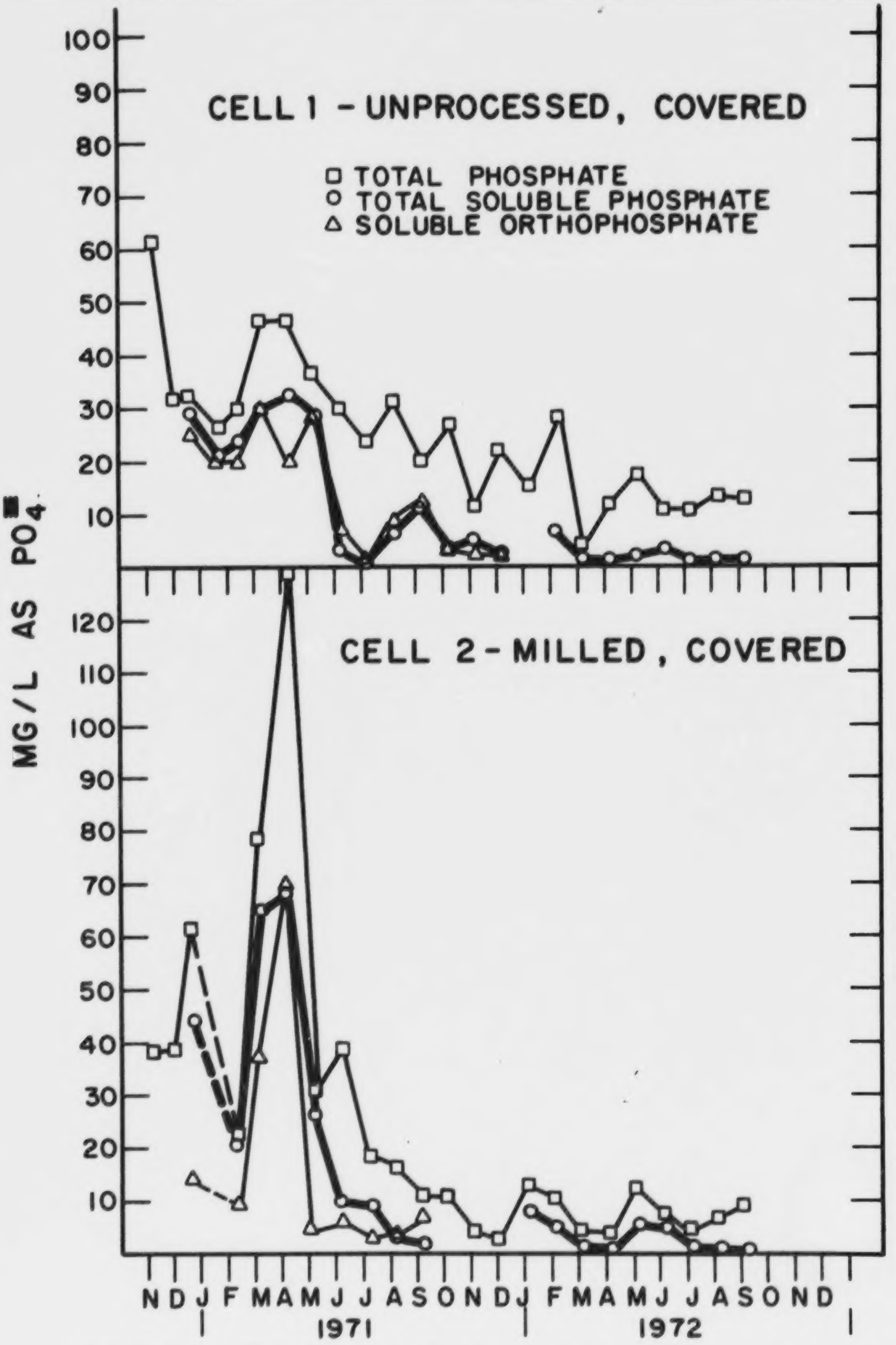


Figure 80. Phosphate Analysis of Leachate From Lysimeter Test Cells (Cells 1 & 2)

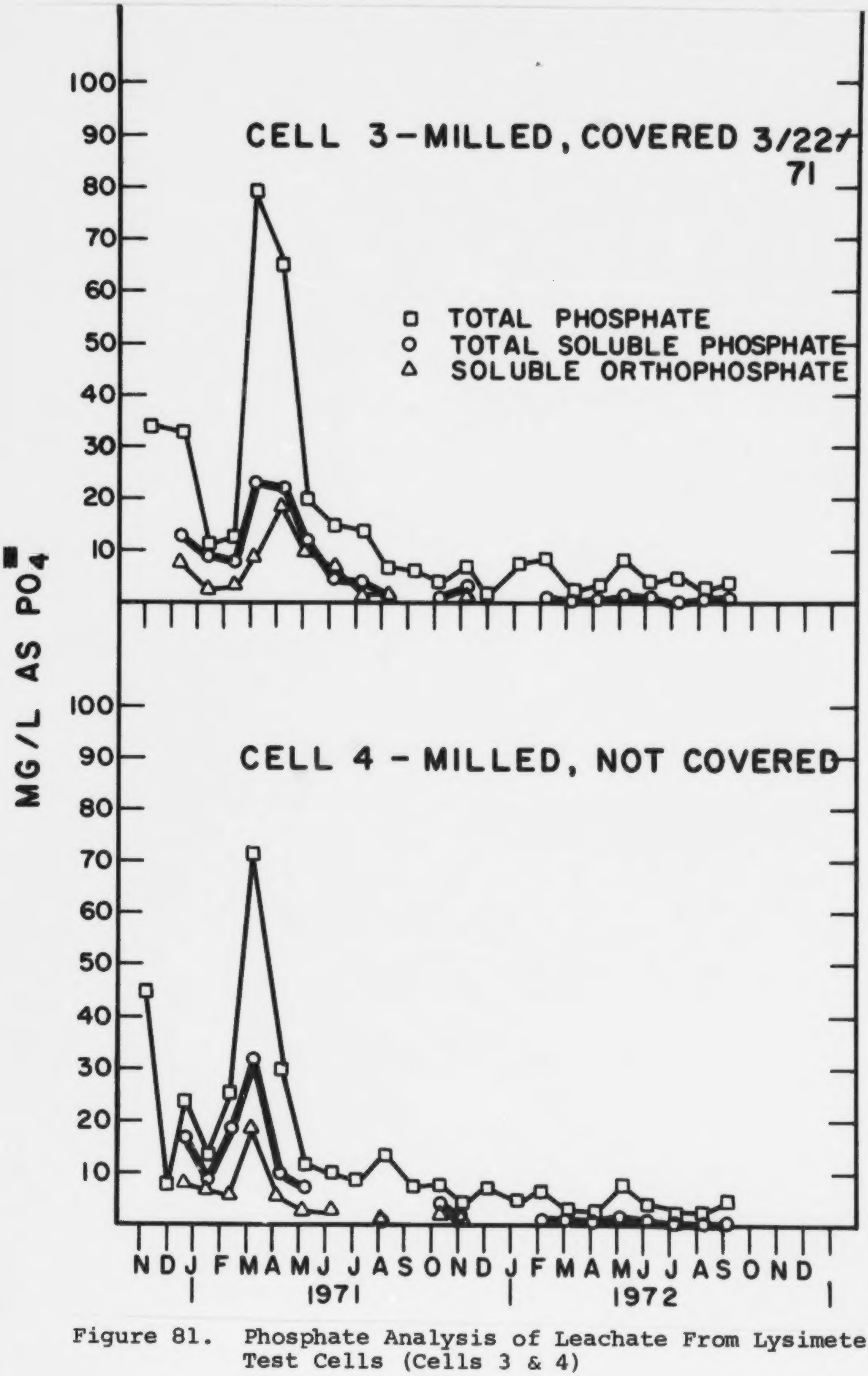


Figure 81. Phosphate Analysis of Leachate From Lysimeter Test Cells (Cells 3 & 4)

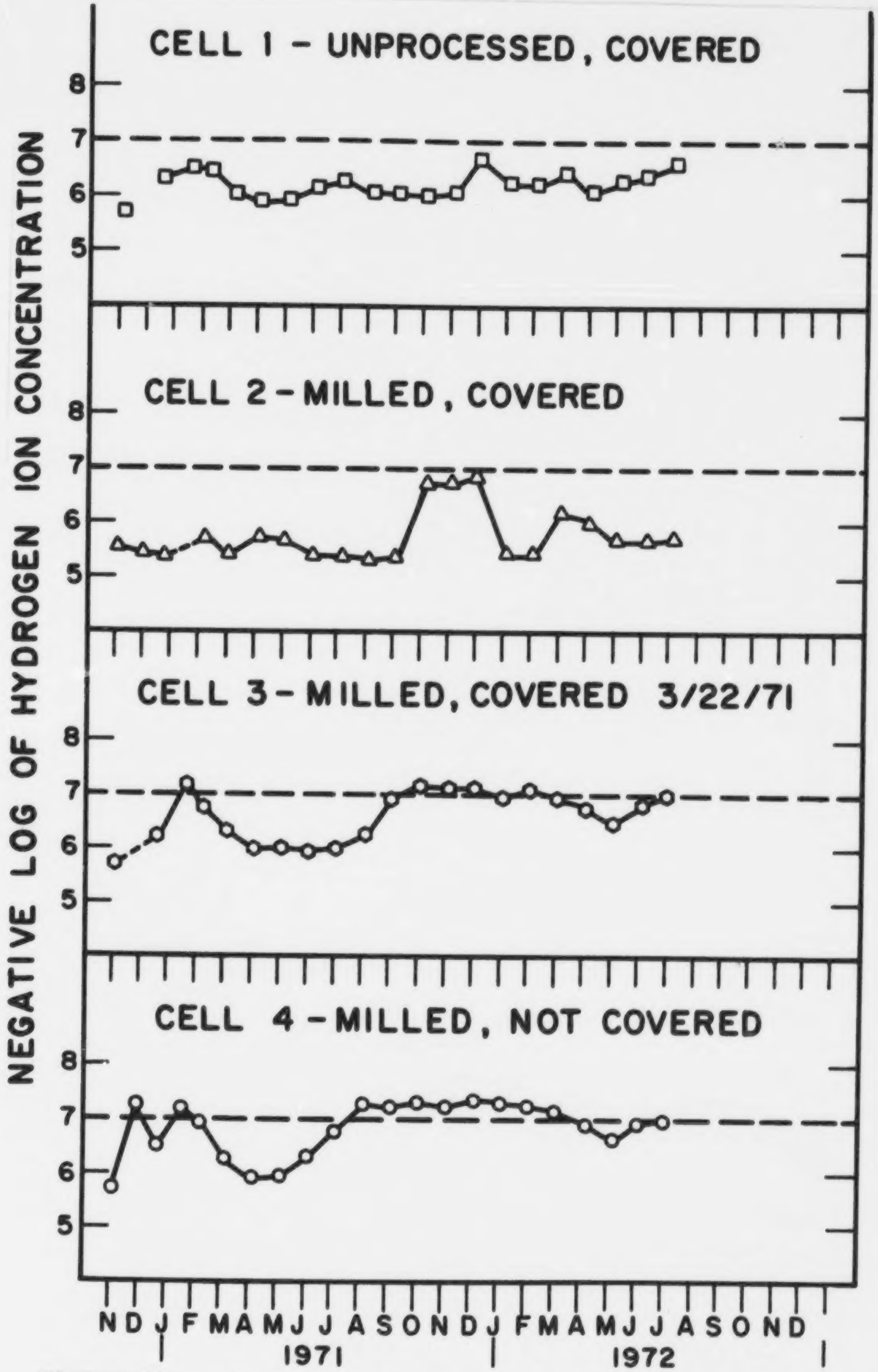


Figure 82. pH of Leachate From Lysimeter Test Cells

anaerobic conditions, and also during aerobic conditions depending on CO_2-H_2O relationships. The reader is referred to the COD section for more discussion of this subject.

Cell 1 - The Unprocessed Covered Cell

The pH in the unprocessed, covered cell 1 has remained acidic. This suggests that organic acids are being produced and that organics are not being reduced to their lowest oxygen-demanding state. The fact that methane gas is not being produced in this cell further confirms this statement. This is important because it indicates that degradation has not been stabilized* to the degree that either the refuse itself or the decomposition processes have reached stable, relatively harmless conditions. Mature anaerobic conditions will result in lower amounts of degradable organics in leachate, and more products of decomposition leaving in the gaseous phase. Assuming gases are freely vented to the atmosphere, such a condition should result in minimal environmental insult.

Cells 2, 3, and 4 - The Milled Cells

The striking effect of soil cover on the degradation process is observed with the pH data from the milled cells. The covered cell 2 maintains an acidic pH, whereas the other two cells more closely approach neutrality. The leachate from cell 4 has been less acidic than that from any of the other cells. This, together with the fact that methane production in cells 3 and 4 has begun, indicate that the degradation process has become relatively stable in these two cells. This is further indicated by the low COD being produced in these cells during the last year or so of monitoring. Cell 2 may have been approaching such a state in the fall of 1971, but the drop in cell temperature or other effects of the soil cover, as discussed in the COD section, possibly set the process back by inhibiting the methane bacteria. Of interest is the fact that methane was observed during the fall of 1971 period but disappeared again and has been observed only sporadically since.

Temperature:

Temperature is of importance in the degradation process because it directly affects the rate of biological activity and to a more limited extent, the physical and chemical leaching processes. The temperature curves (Figures 83 & 84) show that soil cover has an effect on temperature as well as does the seasonal adiabatic temperature.

Soil cover suppressed the temperature in the milled cells such that with cell 2 the temperature curves fairly closely follow those for the unprocessed cell 1. Without soil cover the temperatures are initially

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*Sawyer, C. N., and P. L. McCarty. Chemistry for sanitary engineers. 2d ed. New York, McGraw-Hill Book Company, 1967. 518 p.

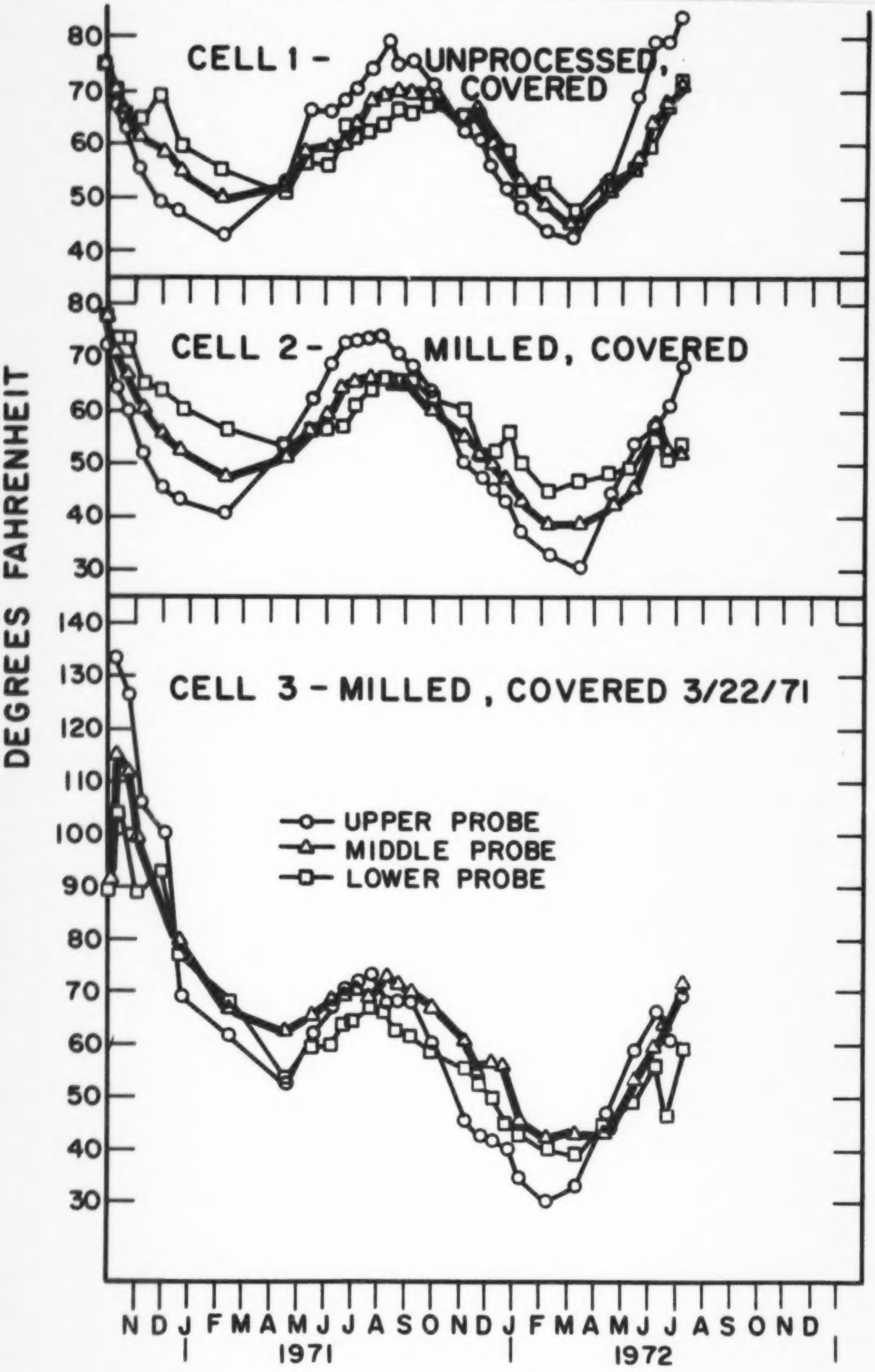

Figure 83. Refuse Temperature in Lysimeter Test Cells (Cells 1, 2, and 3)

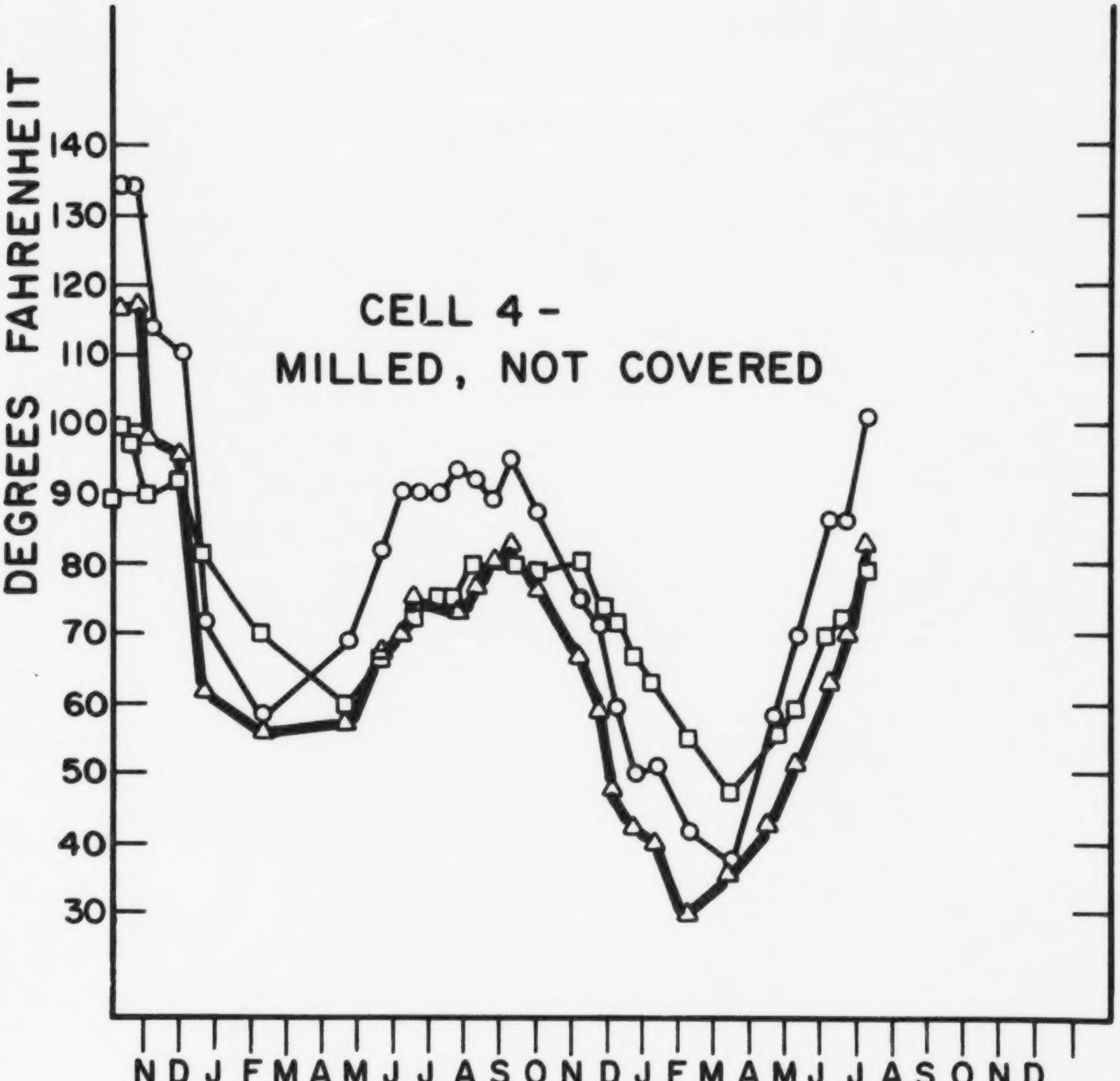

Figure 84. Refuse Temperature in Lysimeter Test Cells (Cell 4)

much higher and stay higher over a long period of time. After this initial period in the winter season temperatures in all cells are in much the same range. In the following summer season, however, the covered cells again are cooler. Of interest is the fact that after being covered cell 3 reverts from a curve much like cell 4 to one much like cells 1 and 2, indicating the cooling effect of the soil cover. Generally the top and bottom temperature probe curves cross the middle curves as the seasons change from winter to summer and back, although with cells 3 and 4 this is not so consistently the case.

Leachate temperature data (**Figure 85**) further indicate the effect of soil cover in lowering the temperature of the cells. The leachate temperatures are lowest in covered cells.

An interesting phenomena concerning soil cover and cell temperature occurred over the first two winters of the project. During the first winter period large areas with no snow cover were prevalent on the then both uncovered milled cells 3 and 4. In contrast, on cells 1 and 2 snow covered the cells all winter and ice patches occurred. During the second winter only cell 4 had bare patches though this was not as prevalent as during the previous winter (note that cell 3 was covered with soil the preceding summer). Again the cells with soil had snow cover all winter, and ice patches were more evident.

In looking at the leachate and cell temperature curves (**Figures 83, 84, and 85**) these temperatures are higher in cells 3 and 4 in the first winter than the second, a fact which contributes to the snow melt. In the second winter, even though cell temperatures are much the same, the lack of soil cover in cell 4 must contribute to the bare spots on this cell. Thus soil cover must keep what heat is available insulated from the snow, or must lower the amount of heat generated, or both.

Cell Moisture:

As with cell temperature, soil cover has a direct effect on cell moisture (**Figures 67 and 68**). Aside from several minor fluctuations, the moisture content generally increases with depth, but with soil cover the difference in moisture between the upper and lower probes is reduced. This indicates that for the milled uncovered cell 4, evaporation rates are greater than in the other cells, where evaporation tends to pull water upward to the cell surface for evaporation. Soil cover, then, serves to insulate the refuse from the sun, and drying by the atmosphere, thereby maintaining a higher moisture level in the upper layers. It seems that the top refuse layer acts like a buffer zone, changing in moisture content over a relatively large range, depending on climatic conditions. In periods of heavy rainfall, this layer becomes saturated and moisture flows downward to bring underlying refuse to field capacity. Conversely, in dry periods the moisture in the top layer is readily lost by evaporation from the large exposed surface area (paper, etc.) and some moisture migrates from lower depths by capillary action to be evaporated at the surface.

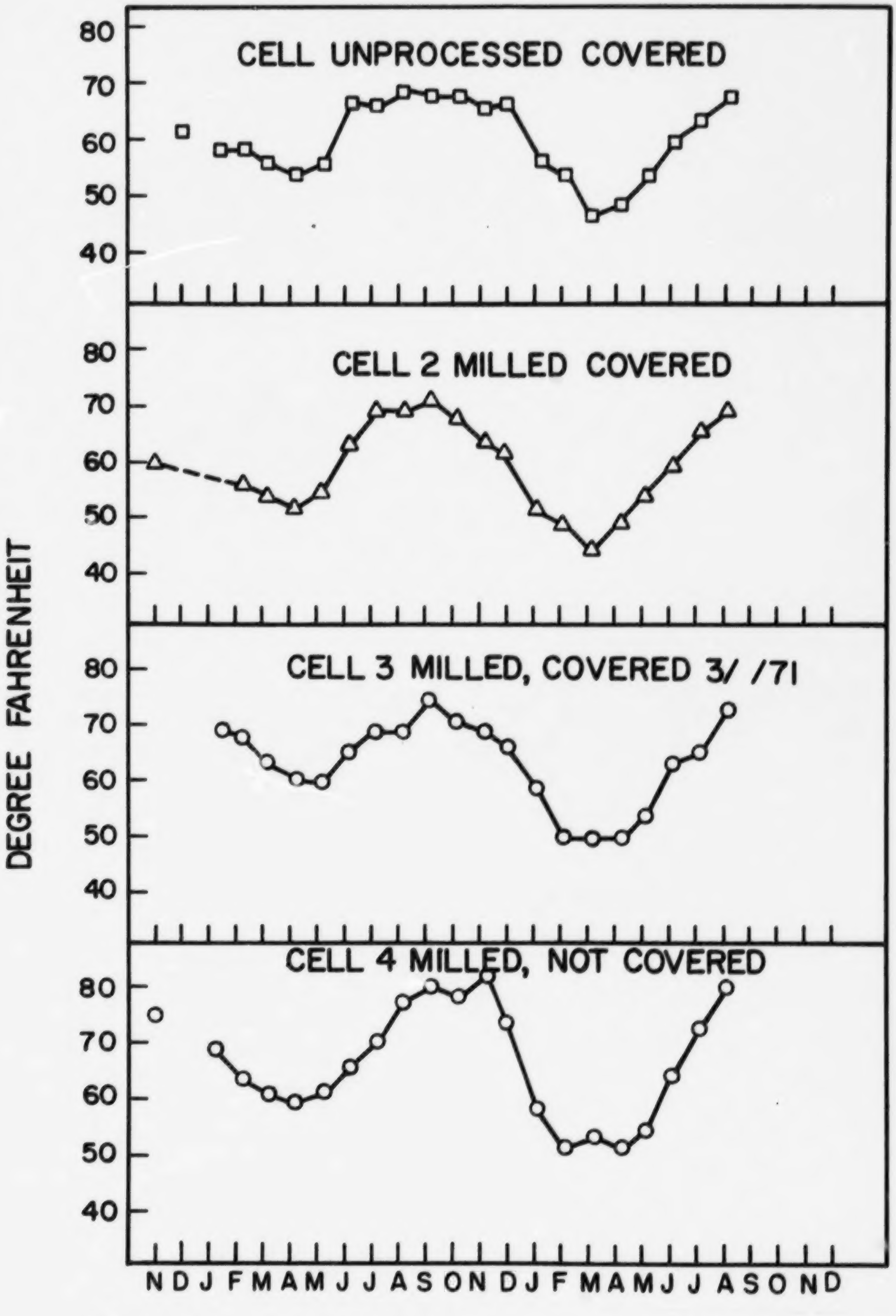

Figure 85. Leachate Temperature From Lysimeter Test Cells

Gas Data:

Four gases were sampled for percent composition: N_2, CO_2, CH_4, and O_2 (**Figures 86 and 87**). Of these, N_2 is not plotted and can be determined by difference. Oxygen is present in all graphs. Since methane is also present on several of the graphs, indicating anaerobic conditions, it is felt that sampling error contributed to the ubiquitous oxygen findings. The error was slight, however, since oxygen values were usually below 1 percent. It is interesting to note that on occasion the percentages of oxygen rose and in several cases stayed at relatively high percentages. These rises usually occurred during or slightly after periods of high precipitation or during spring thaws. This indicates that water percolating through the cell possibly carried oxygen with it to the extent that O_2 was picked up by the gas probes.

Cell 1 - The Unprocessed Covered Cell

The gas data for this cell, **Figures 86 and 87** indicate little difference between the upper and lower probes. Perhaps this is due to ease of gas transfer within the refuse in comparison with the much lower permeability through the soil cover. Another observation is that methane is, for all practical purposes, not being produced in this cell. This indicates that the decomposition process has not stabilized to the degree that the organic matter in the refuse is being decomposed by second stage anaerobic processes.

Also of interest is the fact that the percentage of CO_2 is fairly constant in the cell. Observations from the Biotron studies (Section VI-C) indicate that CO_2 gas is absorbed into leachate to a certain degree as carbonates, and shows up as alkalinity. It is surmised that the curve is constant due to the fact that CO_2 was absorbed according to some kind of equilibrium relationship, thus holding the CO_2 percentage relatively constant.

Cells 2, 3, and 4 - The Milled Cells

The data for these cells are also in **Figures 86 and 87.** Note first the somewhat increased differences between compositions from the upper and lower probes in comparison with cell 1. This may be due to decreased ease of gas transfer in the milled refuse itself (less channeling and voids) and, in the case of cell 4, the lack of the soil cover. Another observation from the graphs is the presence of methane in fairly large quantities in the milled cells. Methane production occurs first in the two then uncovered milled cells (3 and 4) and from then on is generally higher in these two cells than in the milled cell covered immediately, indicating that **mature**, second-stage anaerobic degradation occurs more quickly in the uncovered cell. The fact that methane production is more consistent in cell 3 than in cell 4 and that it is present in larger concentrations seems to contradict the fact that degradation occurs at a faster rate in the uncovered milled cell. However, the presence of oxygen in larger quantities in cell 4 than in cell 3 suggests that air can circulate more readily in and out of the uncovered cell. Thus methane can escape out of cell 4 and oxygen in;

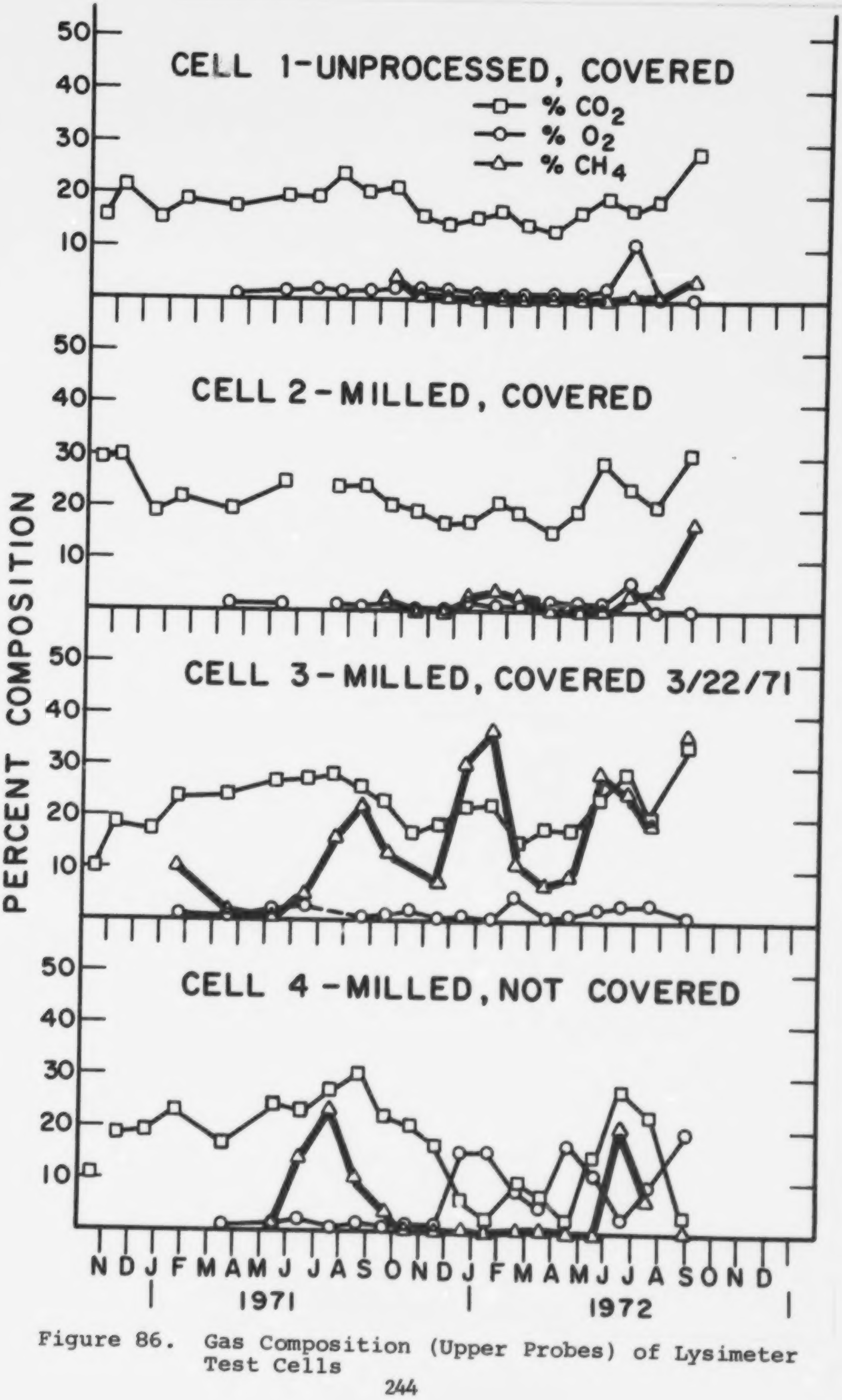

Figure 86. Gas Composition (Upper Probes) of Lysimeter Test Cells

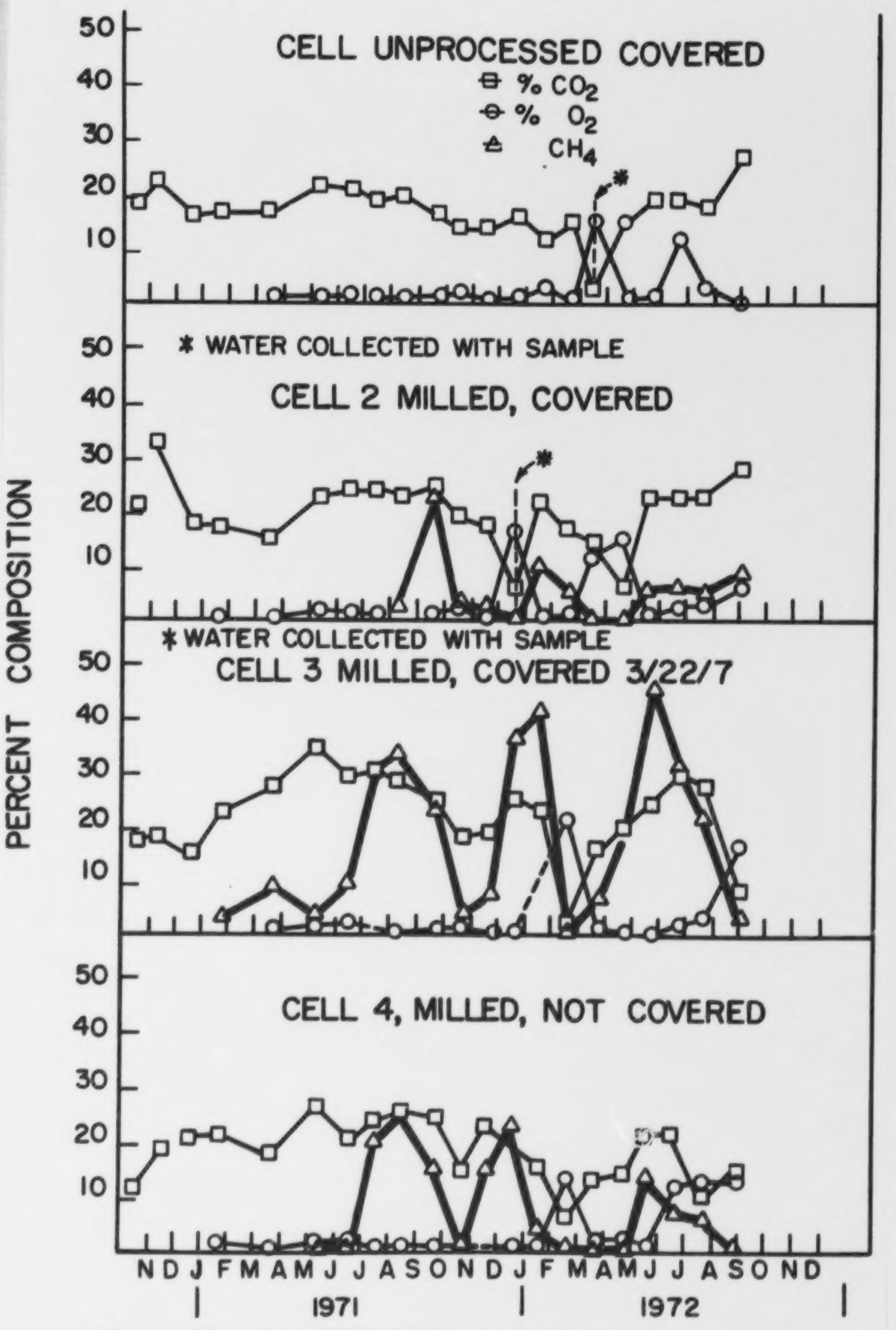

Figure 87. Gas Composition (Lower Probes) of Lysimeter Test Cells

whereas, with cell 3 gas movement is retarded by the soil cover. Thus, the gas compositions measured are products of both gas transfer and gas production factors, and must be interpreted in this light. With cell 2 little methane is produced so this effect of the coil cover is not so apparent.

For the upper probes, the CO_2 concentrations remain fairly steady for cells 2 and 3 (as did cell 1), but fluctuate more for cell 4. Further, the fluctuations with cell 4 seem to be the inverse of O_2 level changes. This may properly suggest a relationship between CO_2 and O_2, which could be the effect of large amounts of infiltration (rain or melting snow) bringing in O_2 and dissolving CO_2. The fact that the CO_2 levels fluctuate more on cell 4, and reached the lowest CO_2 levels observed in this study, suggests that the absence of cover resulted in more direct CO_2 loss to the atmosphere and dissolution in infiltrating waters.

The tendency toward lower CO_2 concentrations in both the upper and lower probes for cell 4 could be an indication of less decomposition taking place, but this is difficult to prove. It is true that the more readily decomposable matter is probably decomposed in the cell by the time the drop in CO_2 is observed, and other evidence such as the leachate data substantiates such a conclusion. However, other factors such as the pH and alkalinity of the leachate could also be causing this trend.

The apparently increased O_2 level in the lower probes of cells 2 and 3, in comparison with the upper probes, is difficult to explain. The CH_4 level was very low or zero when higher O_2 levels **were reported**, as would be expected, which suggests that analytical problems were not the cause. As noted on the graph water was collected with O_2 samples on several occasions. This indicates that high O_2 values at this time may be due to the presence of O_2 in the water and not in the cell per se. It was interesting to observe that the water collected at these times was clear in appearance.

The Water Budget:

As mentioned previously, one of the objectives of this project was to determine the portion of precipitation which becomes leachate, runoff, and evaporation. Data gathered to provide this information are presented in **Figures 69, 88, and 89.**

Precipitation **(Figure 88)** is seen to have occurred at a fairly uniform rate throughout the reporting period.

Cells 1 and 2 show runoff production rates that are almost identical. Such factors as spring thaws and fall rains show up as sharp rises in the runoff curve, whereas flat portions generally occur during the summer periods when rainfall is low and/or the rate of evaporation is high. No runoff was observed on cells 3 and 4 initially. After cell 3 was covered it began to produce runoff and the shape of the curve followed closely the

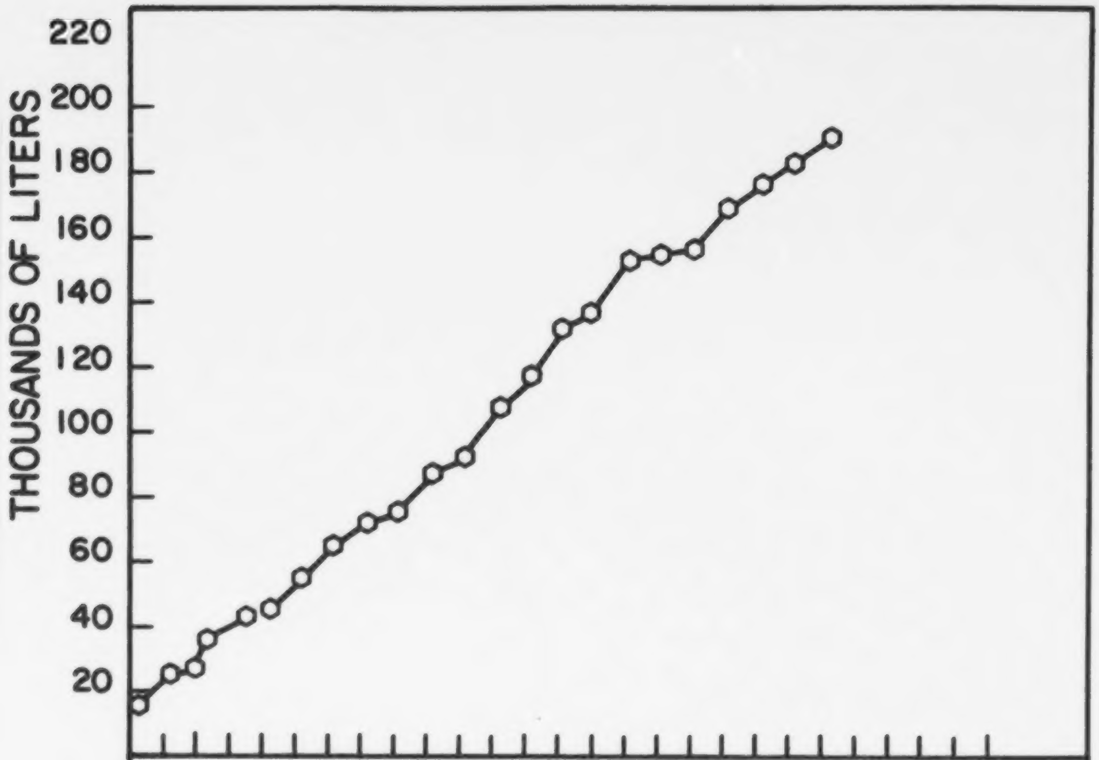

Figure 88. Precipitation During Lysimeter Test

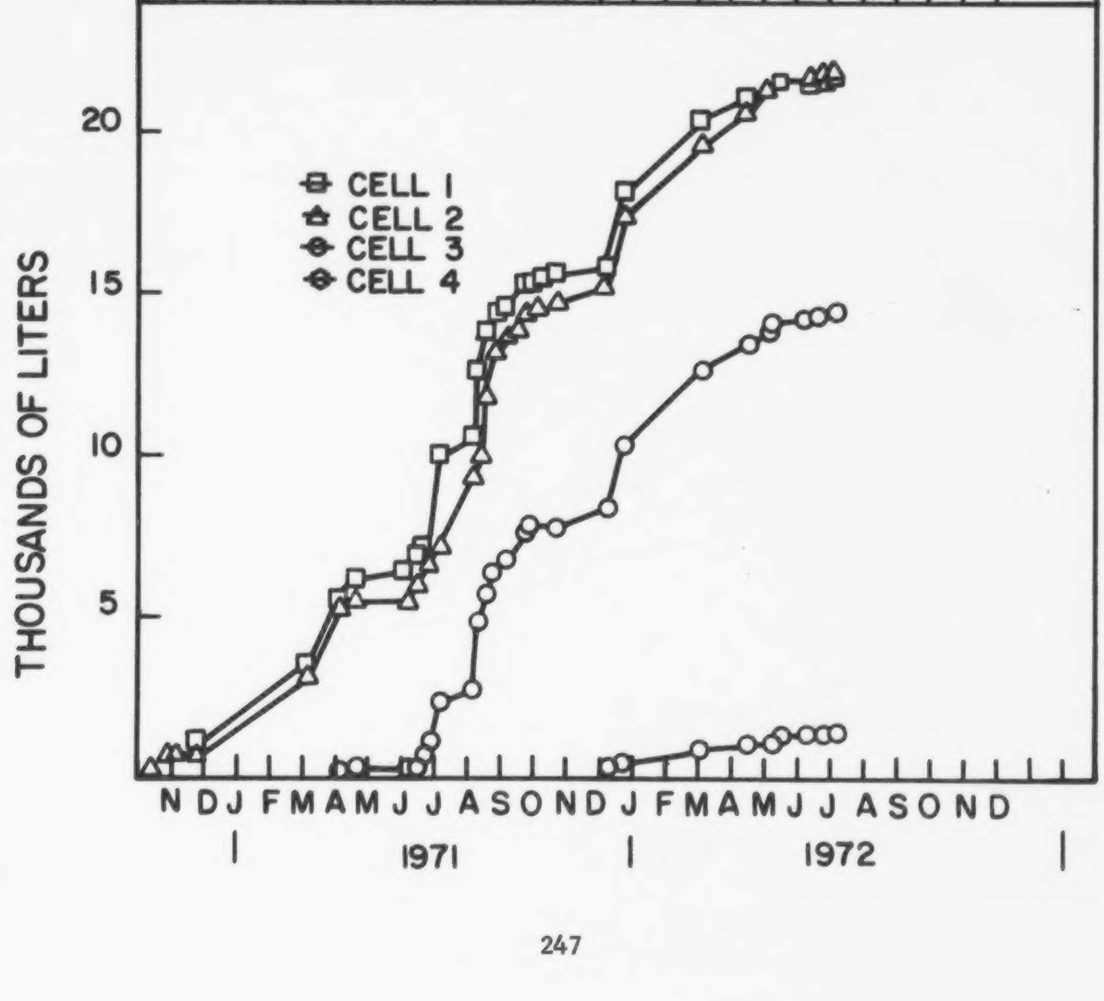

Figure 89. Runoff Measured From Lysimeter Test Cells

shapes of the cells 1 and 2 runoff curves. The rises and level portions occurred at approximately the same times.

Cell 4, the uncovered cell, had no runoff for a year. In December of 1971, when the refuse at the top of this cell froze, some runoff was obtained due to snow melt. It was also observed at this time that the refuse no longer looked simply like shredded paper but was more solidified like a coarse soil. Degradation effects had congealed the upper crust to the point where it could carry some runoff water, but as observed this was very slight. Note that from this point on runoff was occasionally produced, but always at a low level compared with the three covered cells.

Table 51 is composed of data obtained from May 1971 to May 1972. This period is used because by this time the cells seemed to have no more start-up complications and reached relatively consistent performance. Further, all the cells had reached field capacity and were producing leachate regularly.

Table 51

Water Budget Over Period May 1971 - May 1972

	Precipitation (measured) Liters	Runoff (measured) Liters	%*	Leachate (measured) Liters	%*	Evaporation (by difference) Liters	%*
Cell 1	104200	15160	14.5	19018	18.2	70112	67.3
Cell 2	104200	15800	15.1	17551	16.8	70849	68.1
Cell 3	104200	13677	13.1	19249	18.4	71281	68.5
Cell 4	104200	288	0.3	28922	27.7	74990	72.0

*Percent of precipitation.

It is interesting that the evaporation percentages are nearly equal for all four cells, indicating that approximately 32 percent of the precipitation becomes runoff or leachate after field capacity has been reached. The effect of cover is to divide this 32 percent into approximately equal percentages of leachate and runoff.

Without soil cover a larger amount of precipitation infiltrates and becomes leachate, while the evaporation rate increases slightly. The fact that evaporation rates are ghigher in the uncovered cell could be predicted by the fact that cell moisture probes for the upper layer of this cell indicated that it was much drier than in the other cells. It is projected that, as the surface texture of the uncovered cell 4 becomes more congealed and soil-like, as mentioned, the runoff percentage should increase somewhat.

Conclusions:

The following conclusions have been reached subject to the conditions and limitations of this study.

1. Leachate production occurs at a faster rate in milled uncovered cells than in covered cells whether they be milled or unprocessed. The rate of production is not a function of whether or not the refuse is milled, but whether it is covered. Soil cover reduced the fraction of precipitation resulting in leachate approximately in half.

2. Soil cover either directly or indirectly served to keep the refuse cooler, as evidenced by cell and leachate temperatures.

3. Soil cover drastically affected the rate and degree of degradation of milled refuse. In the absence of cover a relatively mature degradation system developed more quickly, which thus reduced the organic pollutional load leaving the refuse in leachate.

4. Covering milled refuse after several months of degradation increased the pollutional loads in leachate, evidently by physically squeezing matter out of the refuse during the application of cover.

5. Milling promotes degradation of a refuse cell whether cover is present or not. This is due to the increased homogeneity of milled refuse and the smaller particle sizes. Thus infiltrate wets more uniformly all of the refuse and promotes more uniform degradation of the readily decomposable organic matter. The result is rapid production of partially degraded matter in leachate; leading to initially high pollutant loads in leachate, followed in a relatively short time by the onset of a mature degradation process, where fewer contaminants are found in the leachate.

6. With the unprocessed cell, comparatively little of the readily decomposable organic matter is exposed for rapid degradation and interaction with the leachate and channeling of leachate through the refuse can develop. The result is lower contaminant production in leachate initially, but continuing degradation at a moderate rate for an extended period. Since it takes much longer for a mature anaerobic degradation system to be developed, more partially degraded matter leaves the refuse as contaminants in leachate.

7. **Table 52 gives data on the production parameters of each cell for the first 22 months since cell construction.**

Table 52

Production Parameters as of July 5, 1972
(actual production in units indicated and as percentage of cell 4 results)

Total Production	Cell 1*		Cell 2**		Cell 3***		Cell 4****	
Leachate (Liters)	29134	67%	29832	69%	35951	83%	43336	100%
COD (Grams)	200753	52%	437910	110%	571052	144%	397731	100%

*Unprocessed, covered immediately
**Milled, covered immediately
***Milled, covered after 6 months
****Milled, not covered

8. Data obtained from the water budget analysis show that 68 percent of the incident precipitation on the covered cells is evapotranspired to the atmosphere. The remaining 32 percent is almost equally divided into runoff and leachate.

On the uncovered milled cell somewhat more evaporation occurs such that 72 percent of the incident precipitation is evapotranspired. In this case the larger part of the remaining 28 percent precipitation becomes leachate; only a minimal amount becomes runoff.

9. Direct comparison of cell 1, the unprocessed covered cell, and cell 4, the milled uncovered cell, confirms conclusions obtained from the Olin Avenue field study. General curve shapes for the two types of refuse cells are as previously obtained. COD concentration curves show a fairly constant level for cell 1 with fluctuations superimposed due to seasonal changes; whereas for cell 4, the COD concentration curve shows an immediate rise followed by a rapid drop to low and relatively consistant levels. Again, as with the Olin data, the two concentration curves cross. Initially cell 4 had COD levels approximately three times those of cell 1. After one year the COD values of cell 4 are less than half those of cell 1.

VI-C - Biotron Studies

This section considers the changes in decomposition arising when refuse is milled and describes a study performed to provide a direct comparison of the decomposition of milled and unprocessed residential refuse without soil cover.

Previous outdoor experiments have been undertaken in Madison and other places to study the degradation of landfilled refuse. These experiments provided valuable data, but almost all had one thing in common--unpredictable and uncontrollable weather conditions. Thus, this experiment was set up with two major objectives: (1) to study the decomposition of refuse under controlled environmental conditions, and (2) to compare the degradation of milled and unprocessed refuse of the same composition and under identical controlled conditions.

The University of Wisconsin-Madison Biotron was used for the experiment. The Biotron is a unique research institution that provides facilities to do tests under closely controlled conditions. It has several rooms which can be programmed individually from a central control. Parameters such as air temperature, humidity, and light can be varied according to a chosen pattern.

This experiment was conducted in two identical compartments in the Biotron--one for milled, the other for unprocessed refuse. The arrangement made it possible to hold the refuse-filled cells under identical conditions and, at the same time, to monitor the degradation characteristics and pollutant production separately. The controlled parameters also made it possible to select conditions that would promote relatively rapid decomposition, thereby reducing the time needed for the study.

Data were collected from three main sources: (a) within the refuse, (b) from the leachate produced, and (c) from the gas produced. Readings of temperature and moisture were taken. Temperature data provided information about the biological activity, while moisture data made it possible to follow the water movements within the cells.

The following tests were run on the leachate: pH, conductivity, solids, hardness (total and calcium), alkalinity, chlorides, total iron, phosphorus (total, soluble, and ortho), nitrogen (ammonia and organic), and chemical oxygen demand (COD). Of the tests conducted, COD and total dissolved solids (TDS) are thought to be the most important because they give a very good approximate indication of the gross organic and inorganic contents, respectively, of the leachate produced. The tests were selected to give a detailed picture of the pollution potential of leachate. In addition, they should provide information about the degradation process. It was also of interest to study correlations between various parameters. The chambers were supplied with a known and constant air flow. The exhaust air was analyzed for CO_2 and hydrocarbons. Gas production data should give information about the bacterial activity as well as more precise data on total production of CO_2 and hydrocarbons from decomposing refuse.

EXPERIMENTAL SETUP

Description of Containers:

Two similar containers, one filled with milled refuse, the other unprocessed refuse, were used for the degradation studies. The containers consisted of 3/4-in. plywood supported by a welded steel frame. To make the containers watertight, all joints and seams were sealed with epoxy, two coats of marine varnish were applied to the plywood, and two sheets of heavy polyethlene were used to line the inside.

Leachate was collected in the bottom of the containers, which were sloped to a stainless steel pipe used as a drain. The bottom part of the containers was filled with 3/4-in. glass marbles to give sufficient support for the overlying refuse and provide free passage of leachate and finer solids while preventing refuse from clogging the drain. Glass was used because it is relatively inert.

Rainfall was simulated in each container by a water sprinkler system. Even distribution of water over the entire surface at a flow rate of less than one gal./min. was difficult, but seemed to be obtained by using three spray nozzles. Distribution of the simulated rainfall was controlled by varying the rate of water flow.

To maintain the densities determined after compaction, the refuse was kept under pressure (Figure 90). This was accomplished by placing a steel frame on top of the refuse and applying pressure by a system of four bolts. The middle bar of the frame was used as a mount for the sprinkler system.

Refuse Composition:

Composition data from an Environmental Protection Agency survey of Madison refuse during the fall of 1970 were used as a standard. (This is not the same survey as detailed in Appendix N.) These data indicated that Madison refuse was close to national averages, and it was thought to be desirable to use refuse of this "typical" composition. Since the experiment was started during the winter, the refuse lacked grass and leaves. To correct the deficiency, the percentages of the other organic components were increased. The "typical" composition and the target composition for this study are shown in Table 53.

To obtain the target composition the refuse had to be sorted by hand. Several loads of residential refuse were separated into the desired categories and the amount from each category needed to fill a container was prepared using the target composition as a guide. Samples from both cells were made in the same manner. The actual refuse composition obtained for the two cells is shown in Table 54 .

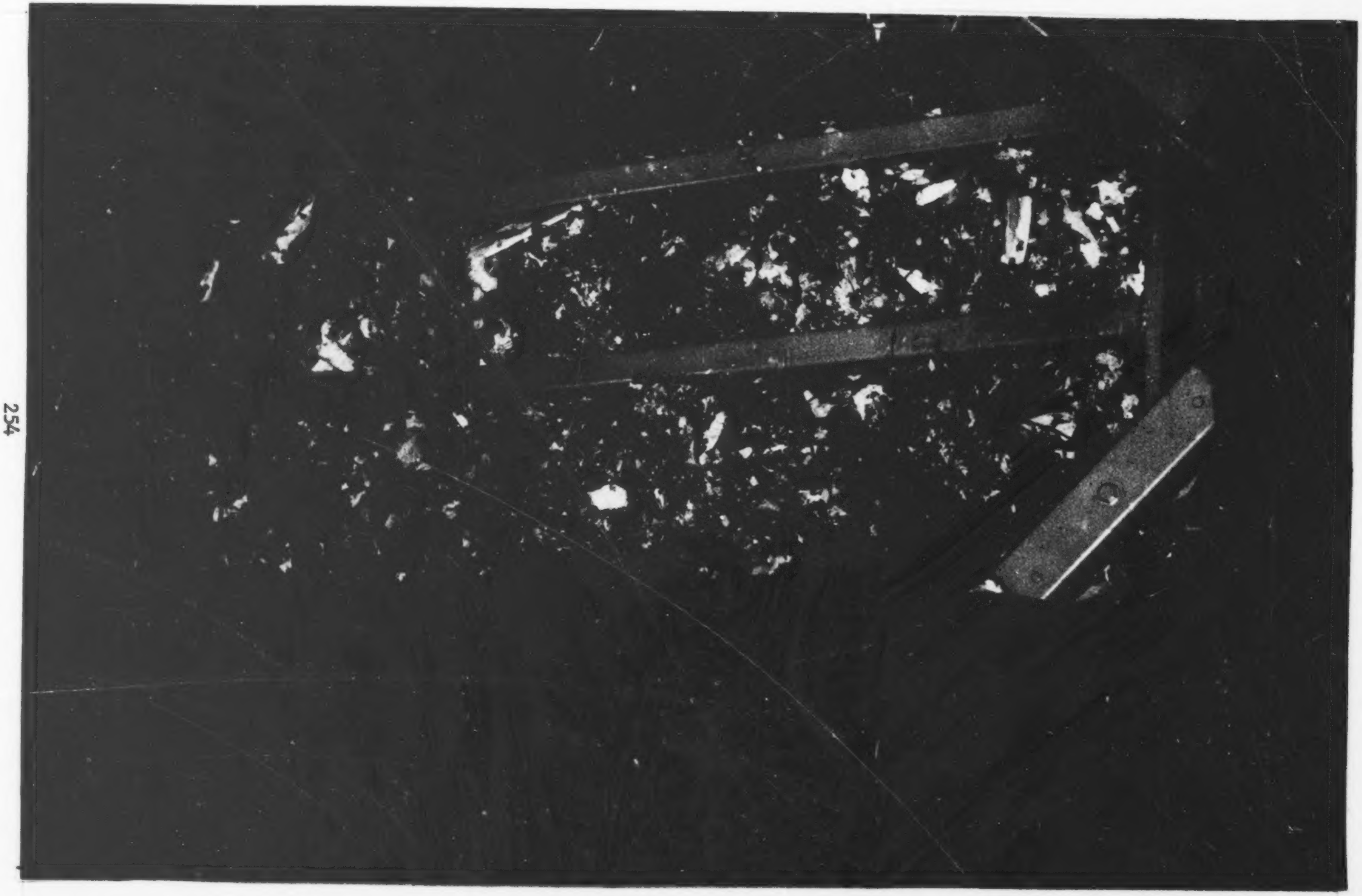

Figure 90. Container Packed With Milled Refuse and Used in the Biotron Studies.

Table 53

"Typical" and Target Composition of Refuse
(Biotron Experiment)

Component	"Typical" Composition	Target Composition
Paper	42.5	46.61
Cardboard	9.8	11.00
Wood, boards	2.2	2.47
Rags, cloth, leather	4.1	4.62
Garbage	9.8	11.00
Cans, metal	7.1	7.10
Bottles, glass, ceramics	15.0	15.00
Plastic	2.2	2.20
Grass, leaves	8.3	0.0
	100.0	100.0

Table 54

Actual Refuse Composition for Biotron Experiment

Component	Milled Cell	Unprocessed Cell
Paper	45.09	45.36
Cardboard	10.65	10.65
Wood, board	2.37	1.94
Rags, cloth, leather	4.45	4.55
Garbage	10.50	10.58
Cans, metal	8.08	8.17
Bottles, glass, ceramics	16.36	16.34
Plastic	2.50	2.41
Total	100.00	100.00
Average moisture on dry weight basis	14.9%	16.1%

The milled sample was prepared using a Tollemache Hammermill. Several specimens were arbitrarily picked for determination of moisture content. The average moisture content of the milled specimens was 14.9 percent based on dry weight. The unprocessed sample was mixed and crushed by a rubber-tired front-end loader to simulate landfill compaction. The material not used in filling the container was milled to get specimens for moisture determinations. The average moisture content of the unprocessed specimens was 16.1 percent.

Filling and Compacting:

The refuse was weighed and placed in the cells in layers. Each layer was evened out and compacted somewhat by hand prior to being compacted by machine. A Universal Press capable of applying a load of 1,000,000 lbs. was used to compact the refuse (Figure 33). Loads applied by the press varied from 5,000 lbs. on the first layer to 10,000 lbs. on the last layer. These loads correspond to pressures of 3.16 to 6.32 psi on the refuse surface. (A medium size crawler tractor will impose about 6 psi of pressure on the refuse surface.)

To have a basis for comparison, equal weights and equal volumes of refuse were placed in each container. To be able to do this, the unprocessed refuse was crushed with a rubber-tired front-end loader on a concrete base to break most of the bottles and flatten the cans. (This usually does not happen in a landfill.) Also, by hand filling the unprocessed cell, the larger articles were selectively placed in each layer which, again, is not the case in a normal landfill operation. Data on weights and densities are given in Table 55.

Table 55

Refuse Weights and Densities in the Containers
(Biotron Experiment)

Parameter	Milled Cell	Unprocessed Cell
Total weight, lbs.	1,190.8	1,263.4
Dry weight, lbs.	1,038.0	1,088.0
Density in place, lbs./cu. yd.	584.0	644.0
Dry density, lbs./cu. yd.	509.0	554.0
Depth of refuse, in.	54.0	53.0
Volume of refuse, cu. yd.	2.04	1.96

As shown, approximately the same weights and volumes were installed in each container. The densities obtained were lower than expected and lower than normal landfill densities. Reasons for this were felt to be the very low moisture content, the fact that no vibration was added as would occur in a landfill during compacting by heavy equipment, and restrictions due to confinement of refuse in a narrow container ("bridging"). The densities of the two cells were fairly close, as was intended.

Installation in the Biotron:

The milled refuse container was installed in the Biotron on February 4, 1971, and the unprocessed container on February 5. The containers were installed in two separate but similar compartments with dimensions 8.40 x 3.95 ft. x 6.80 ft. high. Once in place, they were wrapped in 3.5 in. of fiberglass insulation which covered the outside from the floor to the top edge. This was done to keep the refuse under conditions similar to that which a volume of refuse would experience in the middle of a landfill where, for example, the lateral heat flow will be small compared to the vertical flow.

The sprinkling system was connected to the Biotron's system of demineralized water. The flow rate could be set to the desired level using a rotameter. Sprinkling was done at three different flow rates: 0.45, 0.60, and 0.75 gals./min., respectively. Sprinkling intervals were chosen to give near equal amounts of water at each flow rate. The drain pipe was connected by a tygon tube to a PVC pipe that continued through the cabinet wall, thus allowing leachate collection from the outside.

After installation, the rooms were sealed to make them as airtight as possible. The only air circulation was through the controlled individual air system for each room. The airflow through each room was held at one cu. ft./hr. To provide a supply of clean air of reasonably uniform composition, the air intake for the Biotron is placed 40 ft. above the ground and the air is passed through a filter to remove particles and an activated carbon filter to remove most gas contaminants.

The rooms were run on the same daily climatic conditions throughout the experiment. The temperature varied daily from 75° F (23 °C.) to 95° F (35° C.). The simulated daylight lasted for 16 hrs. with 1/2 hr. dawn and twilight. The light system consisted of twenty 200-watt fluorescent warm lights and three 500-watt incandescent lights. Air humidity was kept at a constant 80 percent. Rainfall occurred once a week, except for a period from June 11 to July 8 when the frequency was twice a week. Total amount of "rain" during the experiment was 65.77 in., which is equivalent to 87.9 in./yr. The climatic condition was designed to approximate a hot summer period with frequent rainfalls which would be expected to accelerate decomposition.

There were several reasons for not including seasonal variations in the climate. Such variations would mean added complications for data interpretation. Furthermore, it was not an objective of this experiment to study degradation under climatic conditions similar to any particular area.

DATA COLLECTION

Three basic types of data were collected: (a) temperature and moisture data from within the refuse, (b) physical and chemical analyses of the leachate, and (c) gas data from the exhaust air by monitoring the CO_2 and hydrocarbon content.

Temperature-Moisture Readings:

Data on temperature and moisture were obtained from probes installed in the refuse mass during filling and compaction. The probes were placed in triplicate at three depths near the center of each container, where care was taken not to place a piece of glass or metal in contact with a probe. In addition, three probes were placed near the end walls. All the wires from the probes were passed through a special opening in order to take readings from the outside. Because of the filling technique used, it was impossible to determine the exact position of the probes with respect to depth until the conclusion of the experiment. At this point the probes were dug out and their location determined.

The probes, Model MC360 Standard Moisture Cells, are manufactured by Soiltest, Inc. Readings were taken with a Soiltest MC300A soil moisture ohmmeter. Moisture determination is based on the resistance between two metal plates in the probe. Temperatures are obtained by use of a thermocouple. Although the probes were designed for use in soil, they have been used in previous landfill experiments and have been found to be the best means available. Previous experience has led to certain techniques for use of the probes in refuse, such as wrapping them in asbestos, using probes in triplicate, and using a revised calibration method. However, even with these improvements, the probes are used only to indicate changes in the moisture content, rather than absolute moisture values.

The probes were calibrated prior to installation. This was done under conditions simulating what they would experience in the cell itself. The probes were held in cages made of metal screen filled with a known amount of refuse. Moisture was added in the form of leachate. Readings were taken at many different moisture levels and the known moisture contents plotted against resistance to give a calibration curve. Temperatures could be determined directly by use of a table.

The probes seemed to give reasonable results for temperatures. The differences between the probes in a triplicate set were typically on the order of 1 to 4° F and the average value is thought to be fairly accurate. Moisture values were more variable. In almost all cases triplicate probes gave moisture content results that differed by 10 to 30 percent. It was very difficult to detect whether these differences were due to actual local differences in moisture content or errors in the probes because of special conditions. The range of moisture content in which the probes gave reasonably reliable results was 20 to 130 percent on a dry weight basis. The upper limit may not cause problems for applications in most soil, but in refuse the moisture content will often exceed 130 percent. This caused some problems when determining the moisture content as the refuse approached field capacity.

The typical sequence for moisture readings with any one probe began with undetectably low readings. After several weeks (3 to 15 depending on the depth) readings went up quickly and, in some cases, passed the highest detectable level after one to three additional weeks. Quite naturally, the largest differences between the triplicate probes occurred during the period of rapid change in moisture readings. A likely reason for this is that the moisture front could reach each probe in a triplicate set at a different time, for the probes were spread a few inches apart horizontally and up to 1 in. vertically.

Temperature and moisture readings were taken twice a week from the beginning of the experiment though June (21 weeks). Afterwards readings were taken once a week. Typical curves relating percent moisture and temperature versus time are shown in Figures 91 and 92. A 12-hr. temperature study was conducted on August 5 to determine whether the daily fluctuations in air temperature affected the temperature within the refuse. Readings were taken at 10:00 a.m., 1:00, 4:00, 7:00 and 10:30 p.m. No daily fluctuations could be detected. The insulation of the container could, therefore, be regarded as sufficient.

Leachate Analysis:

All the "rain" applied, less evaporation loss, had to be stored in the refuse or appear as leachate. The frequency of leachate collection was adjusted so that the storage volume beneath the refuse was not exceeded. This meant collection two to three times per week.

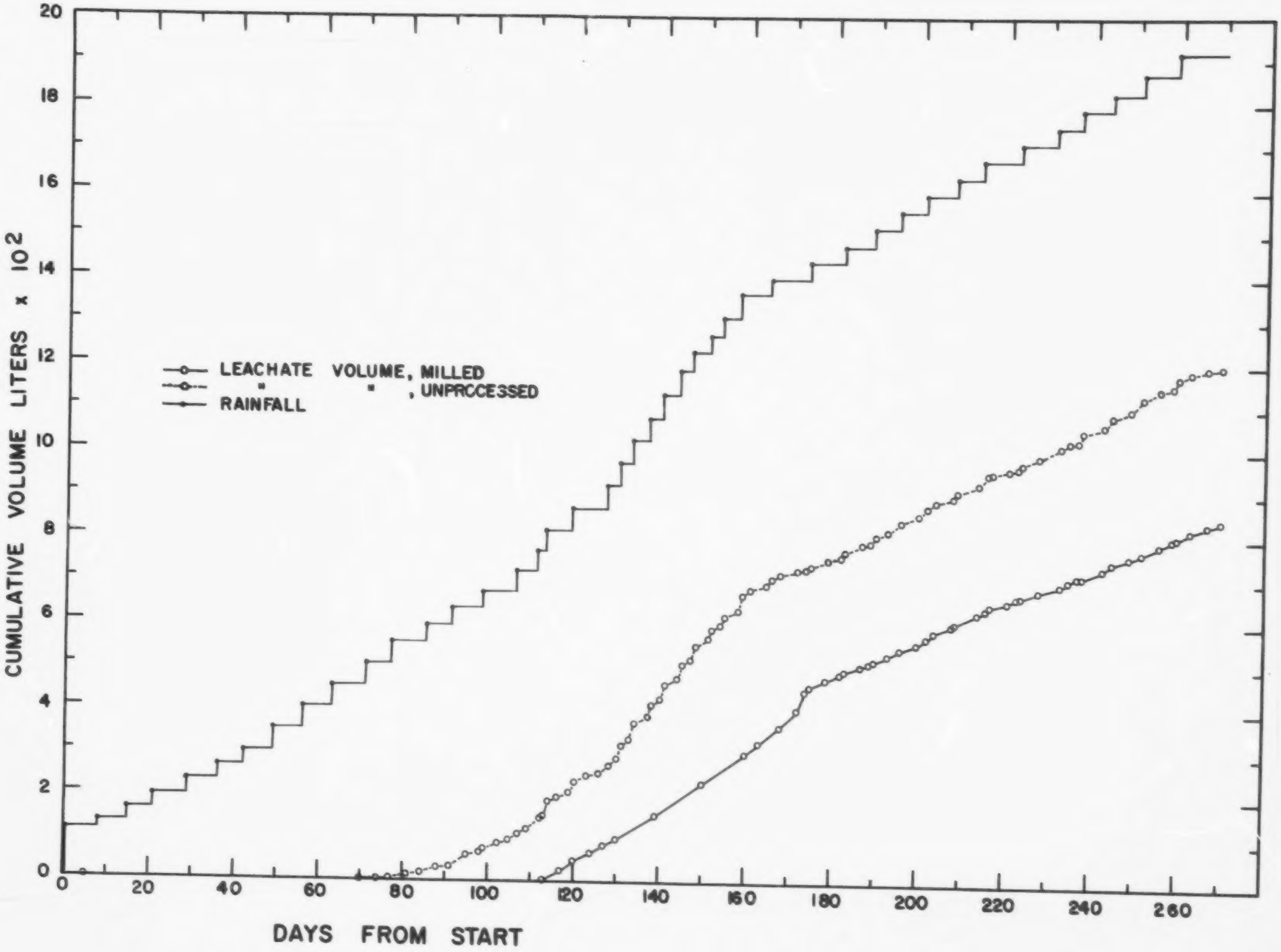

Figure 91. Cumulative Volume of Rainfall and Leachate vs. Time, Biotron Study

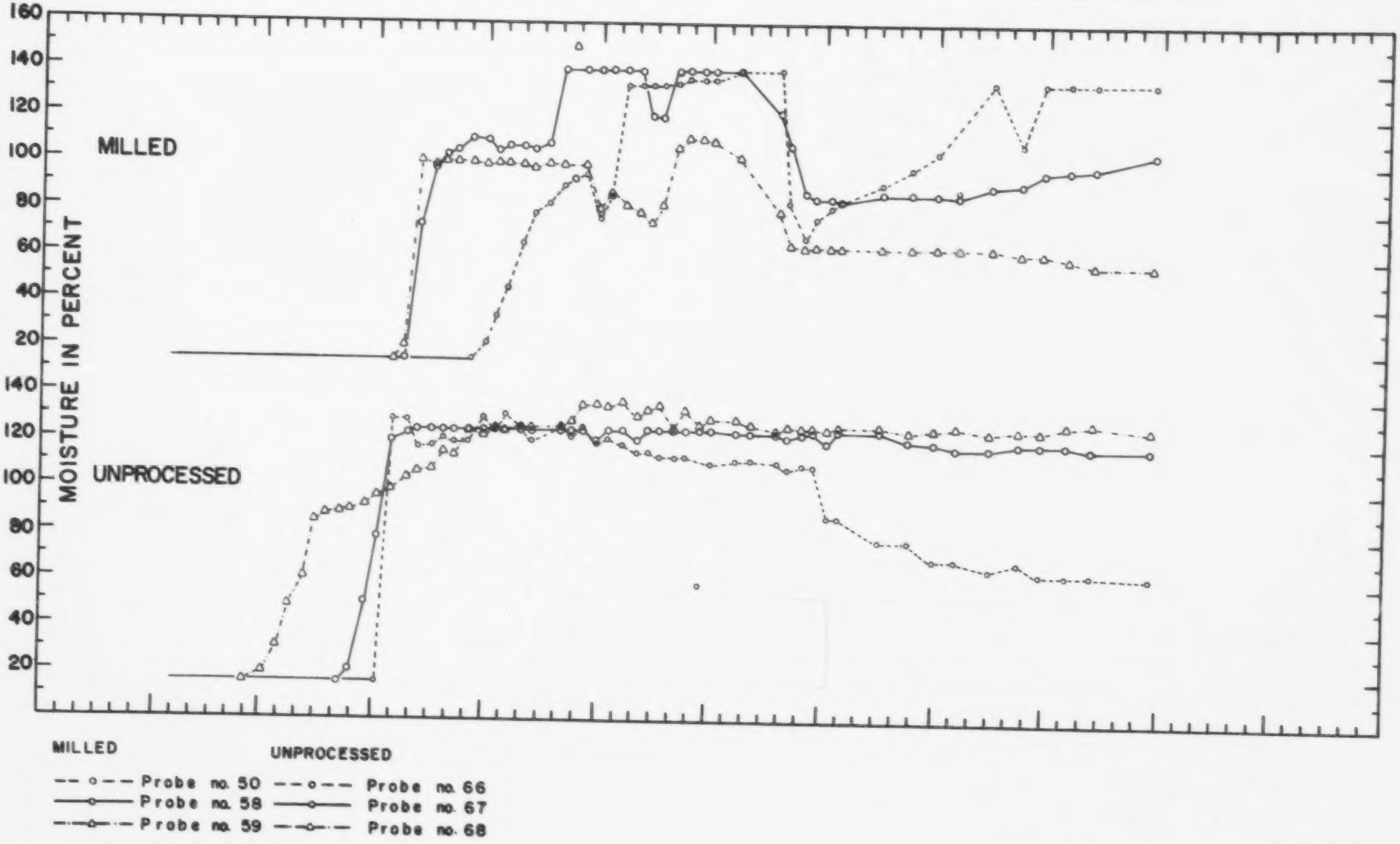

Figure 92. Refuse Moisture Readings at Middle Level, Biotron Study

Leachate samples were taken twice a week, normally on Mondays and Thursdays. It was impossible to run all tests on each sample because of laboratory capacity. The procedure used was to run pH and conductivity on each sample, and to split the remaining tests in two parts, running one-half of the tests on Monday's sample and the remainder on Thursday's sample. Later in the study (from August 5 to October 18) it was found sufficient to run each test every other week; therefore, all the tests were run on one sample from each cell collected every other Monday. During the last three weeks of the experiment an attempt was made to determine the effects of increased rainfall on leachate quality. The frequency of sampling was increased to once a week during this portion of the study.

It was suspected that leachate quality could be related to the length of time from the last "rainfall" to the next sampling. Therefore, some additional tests (pH, conductivity, and COD) were run on leachate samples collected the day after sprinkling and also on samples collected one week after sprinkling but immediately before the next sprinkling. For the milled cell no significant correlation could be found between leachate quality and the time elapsed from last sprinkling. For the unprocessed cell, however, it was found that COD and conductivity values were slightly lower in samples taken one day after sprinkling than in samples taken immediately before the next sprinkling. The results from four such tests showed an average reduction in COD of 6.8 percent, and the variation was from 4.5 to 8.7 percent. Because of this, sampling for analysis was generally done three to four days after sprinkling.

Leachate flowed by gravity from the container and was collected in a 1,000 ml graduated cylinder to measure volume. On days when tests were to be run, the sample was taken from the last one-third of the total leachate volume collected. This procedure was felt to give the most representative sample of fresh leachate. The samples were kept in 500 ml polyethylene bottles or 300 ml glass bottles. Acid washed glass bottles were used when phosphate and iron analyses were to be performed.

Previous experience with leachate analysis has indicated that results will vary due to interferences being present which depend on the amount of suspended matter in the sample. Furthermore, the amount of suspended matter is a function of many uncontrollable factors not necessarily related to the decomposition process. This problem was overcome by using a decanting technique. When a sample was brought in, it was shaken and then left to settle. After four hrs. the supernatant was decanted off. All samples were treated in the same way. Data show that the samples after decanting were low and uniform in suspended solids. This procedure is felt to correspond to actual landfill conditions where most suspended matter will be filtered from the leachate by passing through a few inches of soil.

Normally, pH, conductivity, COD, alkalinity, and hardness were run on the day of collection. In a few instances, they were run on the day after. The remaining tests were then run within a week of collection. The samples were stored in a refrigerator until analysis.

The methods of analysis for the various parameters followed *Standard Methods*[*] and were:

Chemical Oxygen Demand (COD): Standard
Chloride: Argentometric and Mercuric Chloride Methods
Total Hardness: EDTA Titrimetric
Total Iron: Pehnanthroline
NH_3 - N and Organic N: Micro - Kjeldahl
Phosphate: Persulfate Digestion, Stannous Chloride
Alkalinity: pH meter
Total Solids: 25 ml sample
Suspended Solids: Filtration of 25 ml sample

Experience has shown that leachate is especially difficult to analyze. The reason is that leachate contains practically all elements in concentrations exceeding levels found in most wastewaters. This causes interference problems for some tests. In this experiment there were difficulties with the chloride test, especially with leachate from the milled cell. The probable reason was interference from the high iron content (over 300 mg/1). The phosphate analysis was also difficult to perform, especially for soluble and ortho-phosphate. Many of the difficulties were due to the strong color of the samples which tended to obscure the endpoint of the reaction used in the analysis.

Since sample-handling procedures would lead to some aeration, a special test was performed to determine the effect of aeration on two of the analyses; namely: pH and conductivity. One sample bottle was filled carefully and capped. Another sample was aerated by vigorous shaking in a half-full bottle and was left uncapped for several hours. No difference was detected between the two samples. It is unlikely that any of the other parameters used in this experiment should be so much more sensitive to aeration than pH and conductivity as to invalidate the results.

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[*] American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Standard methods for the examination of water and waste water. 13th ed. Washington, Publication Office, American Public Health Association, 1971. 874 p.

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Gas Analysis:

The chambers holding the refuse containers had separate enclosed air systems, as described previously. This arrangement allowed independent analysis of the exhaust air from each chamber. All gas analyses were done directly on samples from the exhaust air pipe. Exhaust air was analyzed for CO_2 and hydrocarbons. CO_2 content was measured by a Beckman infrared analyzer, Model IR315. Total hydrocarbons were measured as CH_4 by a Beckman hydrocarbon analyzer, Model 400. All concentrations were given in ppm by volume. The gas readings were done by the Biotron staff.

The air flow of one cu. ft./hr. was low enough to give detectable increases in CO_2 and CH_4 content and, yet, high enough to maintain a near normal atmosphere in the rooms. The rooms were kept under a slightly positive pressure to avoid any inflow of air. Some difficulty was experienced in getting good gas data. One problem was fluctuations in the composition of the supply air; therefore, the supply air was analyzed as frequently as the exhaust air so that fairly accurate ambient values could be established. Other difficulties with the gas analysis were related to the CH_4 analyzer where a major problem was condensation in the sampling lines brought about by the high temperature and humidity in the test chambers.

INTERPRETATION AND DISCUSSION OF RESULTS

Early in the experiment, some difficulty was experienced with the drain in the milled cell which plugged, allowing leachate to pond. While a portion of the data is missing and may be less accurate for this cell, the information obtained is of sufficient quality and quantity to make the resulting conclusions valid. A small scale experiment was performed to study the effects of ponding on the process of decomposition, and to give additional information to aid in evaluating the data from the Biotron experiment. This study is described at the end of this section.

Physical Properties:

Water Movements Within Cells

As water was sprinkled on the surface some evaporation and percolation occurred. Unlike an actual landfill situation, there was no surface runoff. As each layer of refuse became saturated, surplus water would penetrate deeper into the bed. The main waterfront thus moved downward as the refuse reached field capacity. It is likely that water reached locally further downward than the main waterfront because of inhomogeneity in the refuse bed and the possibility of channeling. In both cases, this is more likely to occur in unprocessed than in milled refuse. The tendency to channel will increase with void size and unprocessed refuse will have larger voids than milled. Channeling and locally advanced moisture fronts are the main reasons for leachate being produced before the whole refuse mass has reached field capacity.

The changes in moisture content were detected by moisture probes placed in the refuse. The moisture data made it possible to calculate the downward speed of the waterfront. The presence of the front was indicated when the moisture value from the first sensing probe in a layer leveled off after a rapid rise. Tables 56 and 57 contain data pertaining to the speed of the moisture fronts. The average speed of the saturated front for the milled and unprocessed cells was 0.50 and 0.658 in./day, respectively. Average penetration for the respective cells was 3.03 and 3.02 in./in. of percolated water.

Table 56

Speed of Moisture Front, Milled Biotron Cell

	Detection of Moisture Front	Travel Time Between Levels (Days)	Distance (inches)	Speed (inches/week)
Refuse Surface	2/4			
Top probes	4/1	56	21	2.62
Middle probes	4/15	14	16	8.00
Bottom probes	5/17	32	14	3.06

Table 57

Speed of Moisture Front, Unprocessed Biotron Cell

	Detection of Moisture Front	Travel Time Between Levels (Days)	Distance (inches)	Speed (inches/week)
Refuse surface	2/5			
Top probes	3/12	36	14	2.72
Middle probes	4/5	24	24	5.84
Bottom probes	4/19	14	12	6.00
Bottom of bed	4/24	5	6	8.40

The unprocessed cell had been producing small amounts of leachate five days after placement. Up to the 77th day, the amount totaled only 4.55 l. Between the 77th and 80th day, production rose to 11.78 l, which indicated that the main moisture front had reached the bottom. The occasional production prior to the 77th day from installation indicates that some channeling occurred.

A distinct difference between the movement of the water fronts through the two cells was shown by the moisture curves. The milled refuse cell showed a more rapid change in moisture from the initial value to the saturated value for each probe. The average time it took the probes to indicate saturation had been reached was 13.3 days for the milled cell and 25.4 days for the unprocessed cell. This indicates that the waterfront was more distinct in the milled refuse.

The milled cell produced leachate at a nearly constant rate while production from the unprocessed cell was closely related to rainfall. This can be seen from the curves in Figure 91. In the case of the unprocessed cell, approximately half of the total leachate volume produced between two rainfalls was produced during the first 24 hrs. after the rain. Direct channeling cannot be the main reason for this. If so, one would expect a more dilute leachate shortly after a rainfall than later in the period, but leachate analyses showed only a slight difference. The explanation must be that unprocessed refuse is more permeable than milled refuse.

The above results indicate that unprocessed refuse will reach field capacity faster than milled under similar environmental conditions.

The probable reason for this can be found in the difference in evaporation rates, which is discussed below, since no significant difference was found with respect to inches of penetration per inch of percolating water. The computed value of 3 in./in. percolating water will not, of course, be generally applicable.

Evaporation and Water Holding Capacity

Since the volume of all water entering as rain or leaving as leachate was recorded, it was possible to set up a water balance and compute the amount of evaporation. To eliminate the problem of water storage within the refuse, the water balance was started after field capacity had been reached. May 16 was selected as the starting date for the unprocessed cell because leachate production and the moisture probes indicated that field capacity had been reached at that time. For the milled cell it was necessary to start from August 5, to avoid the effects of ponding and drainage of surplus water. The results are presented in Table 58.

Table 58

Calculation of Evaporation Rates
(Biotron Experiment)

Period	Days	Total Rain (liters)	Average Rain (liters/day)	Total Leachate (liters)		Average Leachate (liters/day)		Leachate In Pct. of rainfall		Evaporation (in pct.)	
						M	UP	M	UP	M	UP
5/6 - 6/11	36	271.2	7.53		219.1		6.08		80.8		19.2
6/11 - 7/5	24	364.0	15.18		312.3		13.02		85.9		14.1
7/5 - 8/5	31	208.2	6.72		192.8		6.21		92.5		7.5
8/5 - 9/6	32	196.3	6.14	140.9	168.5	4.40	5.26	71.7	85.8	28.3	14.2
9/6 - 10/6	30	154.4	5.15	113.9	142.0	3.79	4.73	73.8	92.0	26.2	8.0
10/6 - 11/1	26	131.7	5.06	104.8	132.9	4.03	5.10	79.6	101.1	20.4	1.1

At the end of the experiment the moisture content (dry weight basis) as determined on two samples from the milled cell was found to be 136.3 and 101.5 percent. The average moisture content was 118.9 percent. The average value cannot be regarded as very accurate because of the large difference between the two samples. By using the initial and final moisture values, amount of rain, and volume of leachate produced, the average evaporation of the milled cell (over the entire test period) was calculated to be 30.3 percent.

No final moisture test was run on the unprocessed refuse because of difficulties in getting a representative sample; therefore, the average evaporation of the unprocessed cell was calculated assuming a final moisture content of 121 percent as indicated by the moisture probes. Using the same method as used on the milled cell, the average evaporation was calculated to be 10.3 percent.

In this study, both milled and unprocessed refuse were kept uncovered. Therefore, the difference in evaporation must be attributed to the difference in physical properties of the refuse due to milling. The large variation in evaporation rates found for the unprocessed cell, as shown in Table 58, is probably due to variations in total moisture held within the refuse, rather than actual changes in evaporation rates.

Comparison of evaporation rates given in Table 58 shows that the milled cell had rates 2 to 3 times higher than the unprocessed cell. This proved to be an important factor when considering the total production of leachate and pollutants. There are probably several factors affecting the difference, including: (a) milling results in more effective surface area for evaporation, (b) milled refuse has more water-holding capacity, and (c) the finer void system in the milled refuse may improve the upward transportation of moisture.

Under field conditions, evaporation rates will be highly dependent on the local climate. It is felt, however, that the evaporation rates found in this study are low compared to what would be found under most real climatic conditions. Reasons for this are the extremely high humidity together with the frequent and "heavy" rainfalls that were used throughout this study.

Although there was a rather large variation in the results from the moisture probes (Figure 92), it was possible to find average values from the graphs of the moisture readings. These average values determined on a dry weight basis are presented in Table 59.

Table 59

Average Moisture Content - Biotron Cells

	Percent Moisture at Saturation				Overall Average
	Top Probes Side	Top Probes Center	Middle Probes Center	Bottom Probes Center	
Unprocessed cell	108	128	125	125	121.0
Milled cell	123	153	124	136	134.0

It was also possible to estimate the average moisture content at the time when leachate production started. For the unprocessed cell, this calculation gave:

Rain added up to April 24	550.0 liters
Evaporation: 0.10 x 550	55.0 l
Water that entered the refuse	495.0 l
Initial moisture content 16.1%	79.5 l
Total amount of water in the refuse	574.5 l

Dry weight of the refuse was 494 kg, which gives an average moisture content of $\frac{574.5 \times 100}{494}$ = 116 percent. A similar calculation for the milled cell gave an average moisture content of 138 percent. The data thus indicate that milled refuse had a higher moisture content at field capacity than unprocessed refuse.

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Temperatures

Moisture and temperature were recorded by the same probes (Figure 93). Of particular interest are the relatively constant temperatures and the low peak values compared to results from other studies done at Madison and found in the literature. Both cells showed an initial peak at the level of the top probes. The low peak temperatures, particularly at lower depths, suggest that the biological activity was mainly anaerobic at these levels. Data on peak temperatures are given in Table 60.

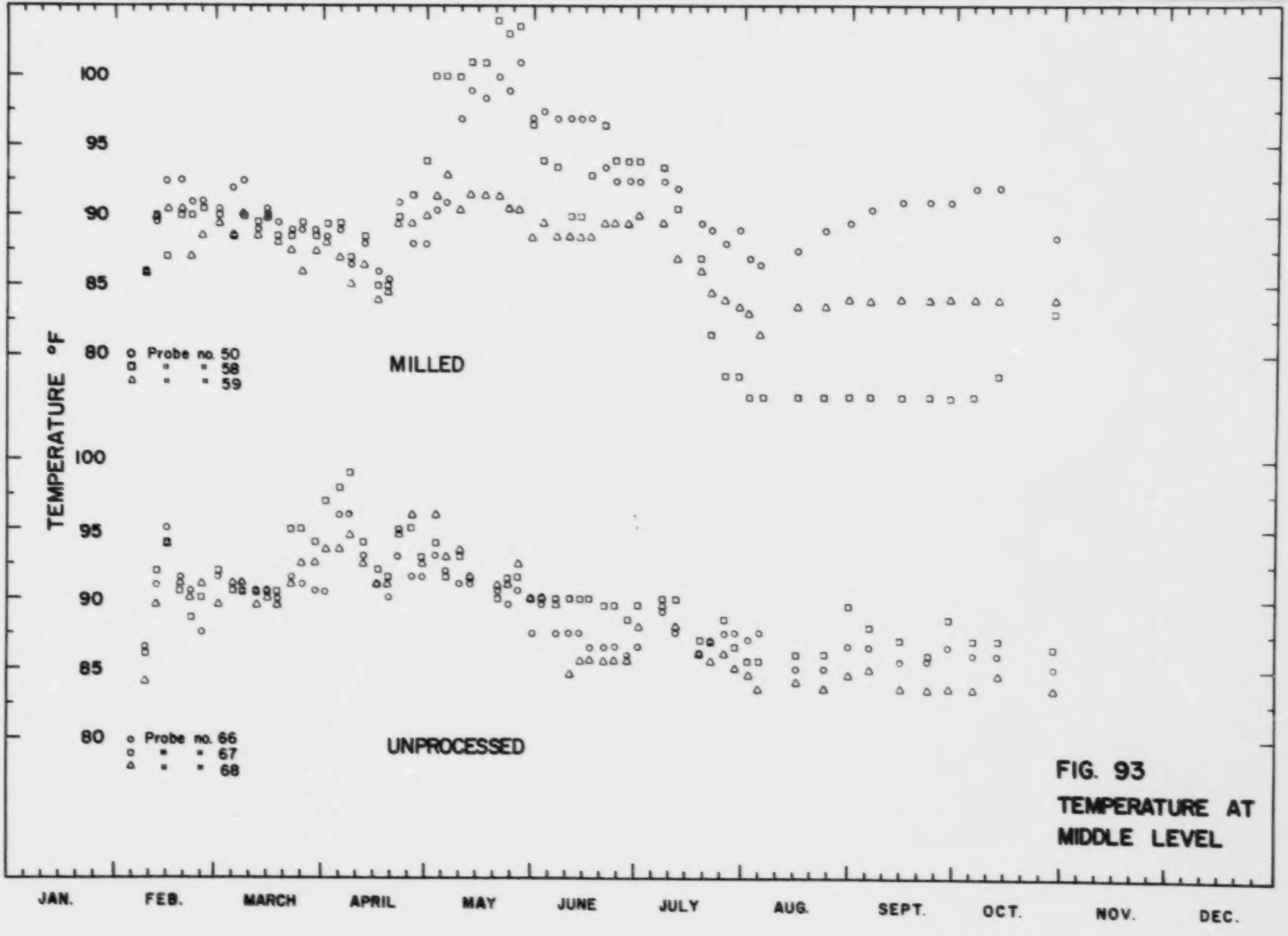

FIG. 93
TEMPERATURE AT
MIDDLE LEVEL

Fig 93

Figure 93. Refuse Temperature at Middle Level, Biotron Study

Table 60

Peak Temperatures in the Refuse
(Biotron Experiment)

	Peak Temperature °F		Days Elapsed	
	Milled	Unprocessed	Milled	Unprocessed
Top Level	101	102.5	7	7
Middle Level	102	96.5	106	63
Bottom Level	95	90.0	147	154

There was a definite time relationship between temperature and moisture. For the middle and bottom levels the rise in temperature coincided with the increase in moisture as the wetting front reached that level. It is important to note that the temperature rise was sharper for the middle level than for the bottom and also more marked for the milled than for the unprocessed cell. This pattern reinforces what was observed for the water movements described earlier in this chapter. The coincidence between temperature rise and increased moisture indicates a close relationship between bacterial activity and moisture content.

During the first 3 months, temperatures generally seemed to decrease with depth. After that time no such relationship could be found. After about 5 months a general decrease in temperature was noted for both cells. The explanation for this temperature drop could involve a decrease in biological activity because most of the readily fermentable material had been removed.

Settlement and Degradation

At termination of the experiment, settlement of the refuse was determined by measuring the vertical movements of the four corners of the steel frame lying on top of the refuse. No settlement was found for the unprocessed refuse. In the milled cell the average settlement was 0.66 in. Hence, the volume reduction was only 1.23 percent.

Little evidence of degradation was found in the unprocessed refuse. Printed paper was still easily readable and even orange peel could be identified. In the milled cell considerable change was noticed in the top 2 to 3 in. This portion was dark brown in color and had a mulch-like appearance. Deeper in the refuse bed little evidence of degradation could be found.

Evaluation of Leachate Data:

In most instances the polluting potential of leachate is expressed in terms of concentrations of various substances, as in mg/1. Usually, numerous graphs of concentration vs. time are plotted to give an indication of the relative strength of the leachate produced. Peak values are also cited to show that leachate is stronger than most municipal, and even some industrial waste waters.

The above information can be and often is very misleading. For instance, a COD concentration of 50,000 mg/1 is of little concern if only a negligible amount of leachate is produced. Conversely, leachate with a much smaller COD concentration can be very damaging if produced in large volumes when compared to the dilution water available.

With these thoughts in mind, graphs are shown indicating the total amount of pollutants produced (grams) and the total volume of leachate produced (liters) on a cumulative basis. It is felt that these graphs will present a much more meaningful indication of the polluting potential of the leachate produced by the milled and unprocessed cells. Also included in this section are a few selected plots of concentration vs. time and total production vs. time. These plots will serve to illustrate that the use of peak concentration values and of graphs portraying concentrations in general can be very misleading and that tests in which the total pollutant production can be computed are necessary for meaningful conclusions.

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Grams vs. Volume

Graphs of the summation of the grams produced for each pollutant vs. the summation of leachate volume are shown in Figures 94 through 98. The shapes of these graphs are very different from concentration vs. time plots.

Comparison of the milled and unprocessed plots for each parameter shows that the unprocessed cell produced about 1.4 times as much leachate as the milled cell did. The difference is accounted for in the fact that the milled cell had a higher field capacity and an evaporation rate almost three times as large as the unprocessed cell. Initially the leachate from the milled cell was of average volume but high in concentration of pollutants; therefore, production vs. volume curves for this cell are very steep during these first stages of leachate production. In contrast, initial volumes of leachate produced by the unprocessed cell were much smaller, as were concentrations; thus unprocessed curves are not as steep as milled curves for the same period. In the case of COD, alkalinity, organic nitrogen and NH_3 nitrogen, the curves eventually converge and either cross

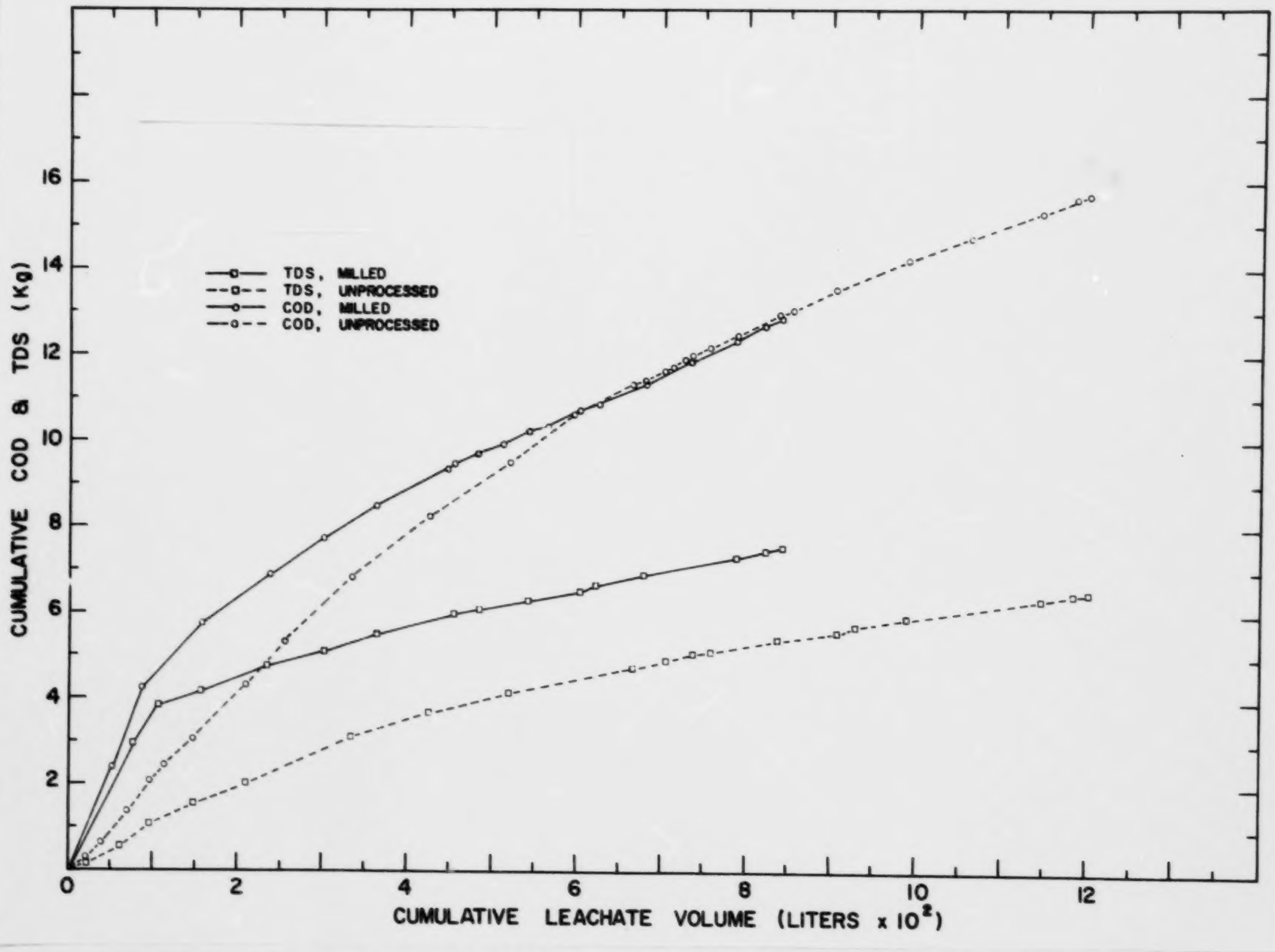

Figure 94. Cumulative COD and TDS vs. Cumulative Leachate Volume

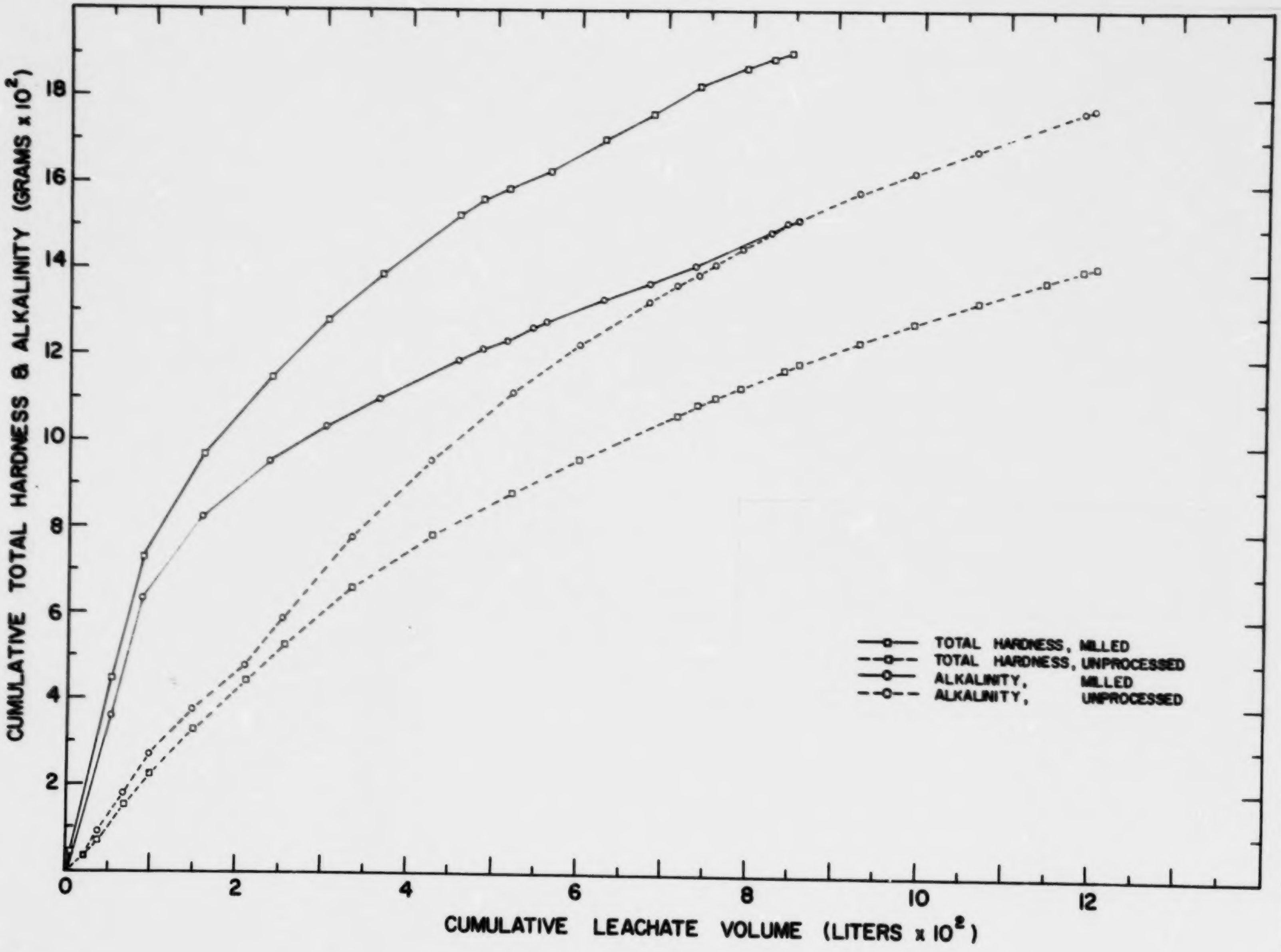

Figure 95. Cumulative Total Hardness and Alkalinity vs. Cumulative Leachate Volume

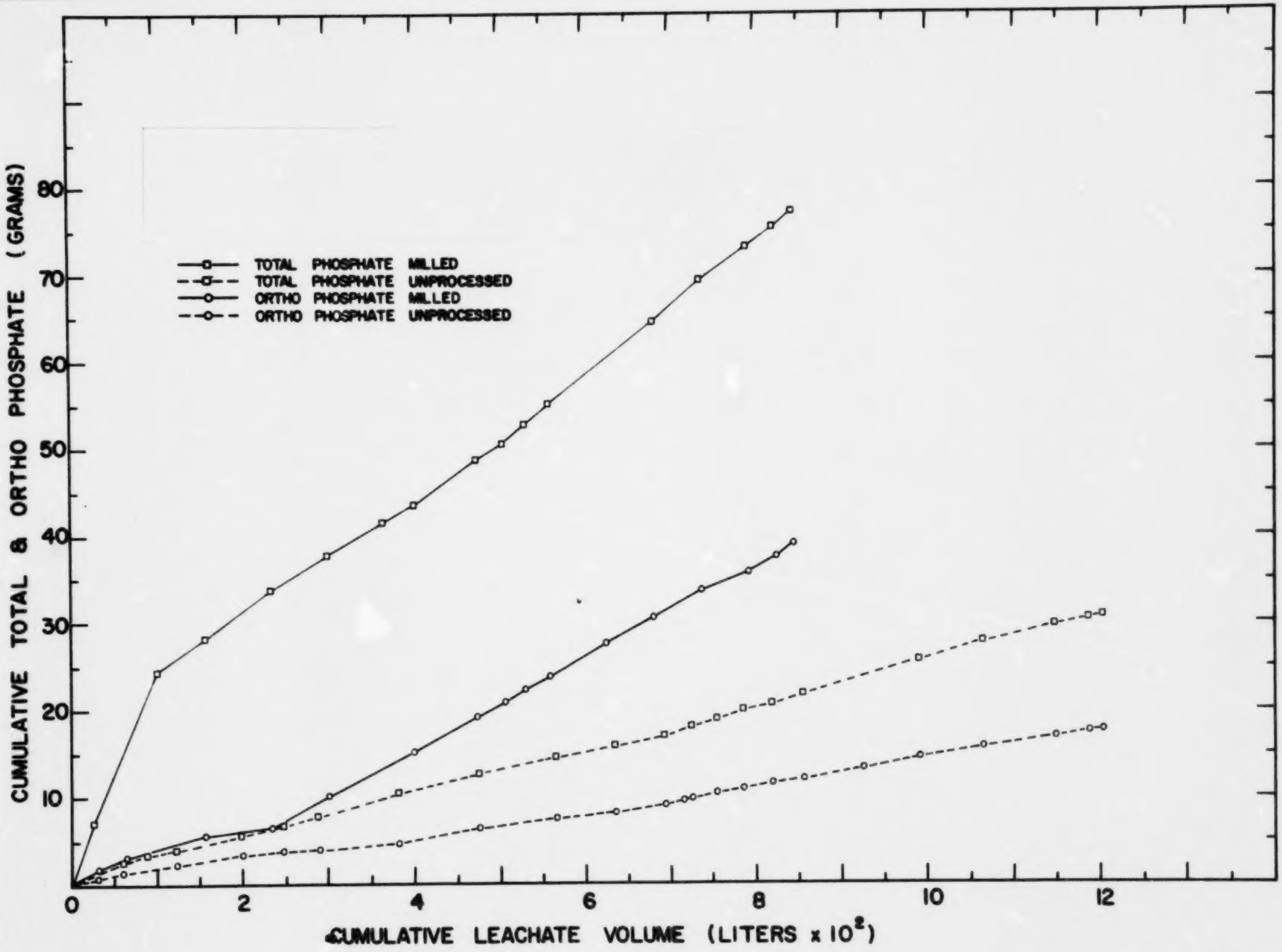

Figure 96. Cumulative Total and Ortho Phosphate vs. Cumulative Leachate Volume

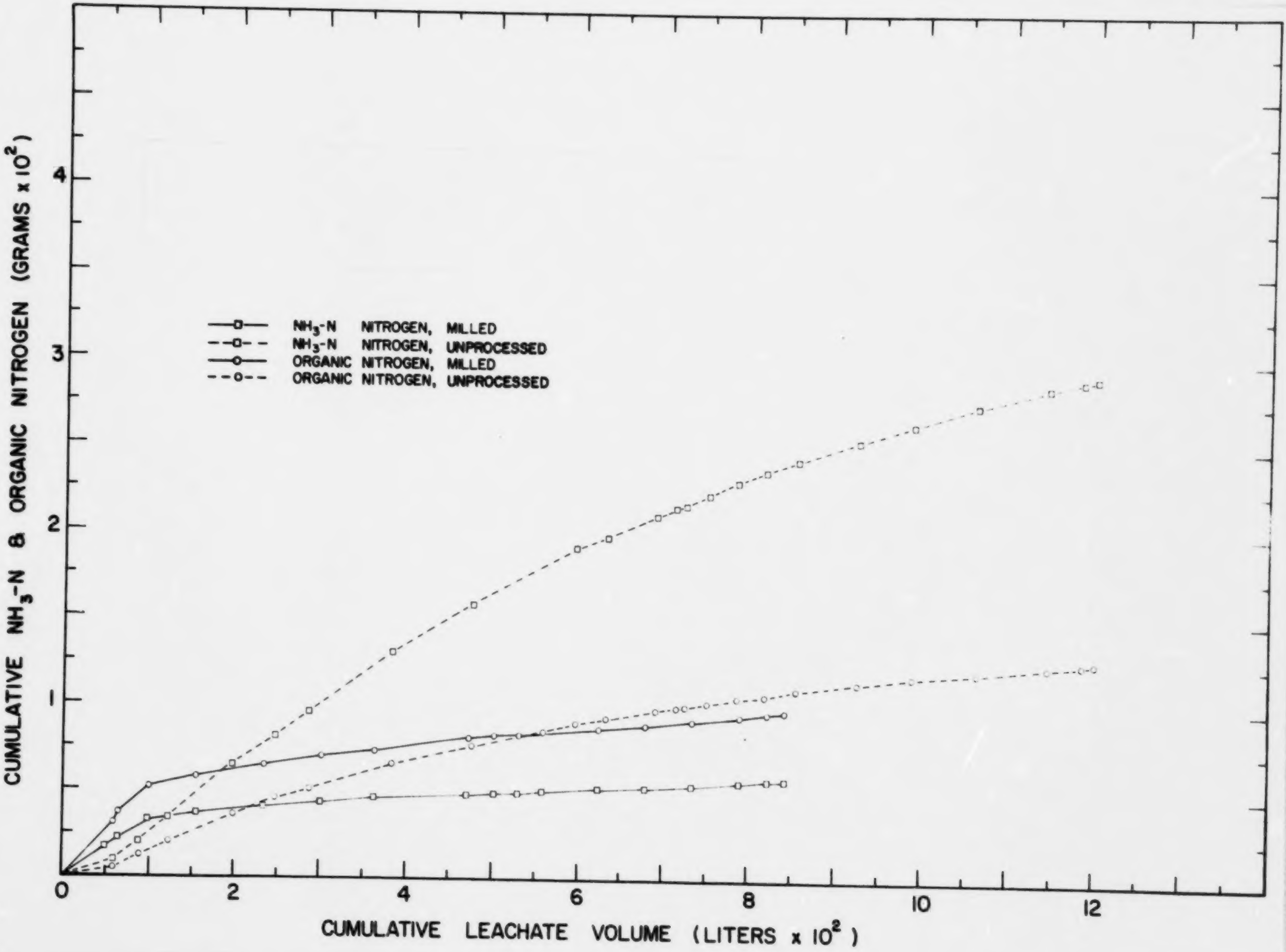

Figure 97. Cumulative NH_3-N and Organic Nitrogen vs. Cumulative Leachate Volume

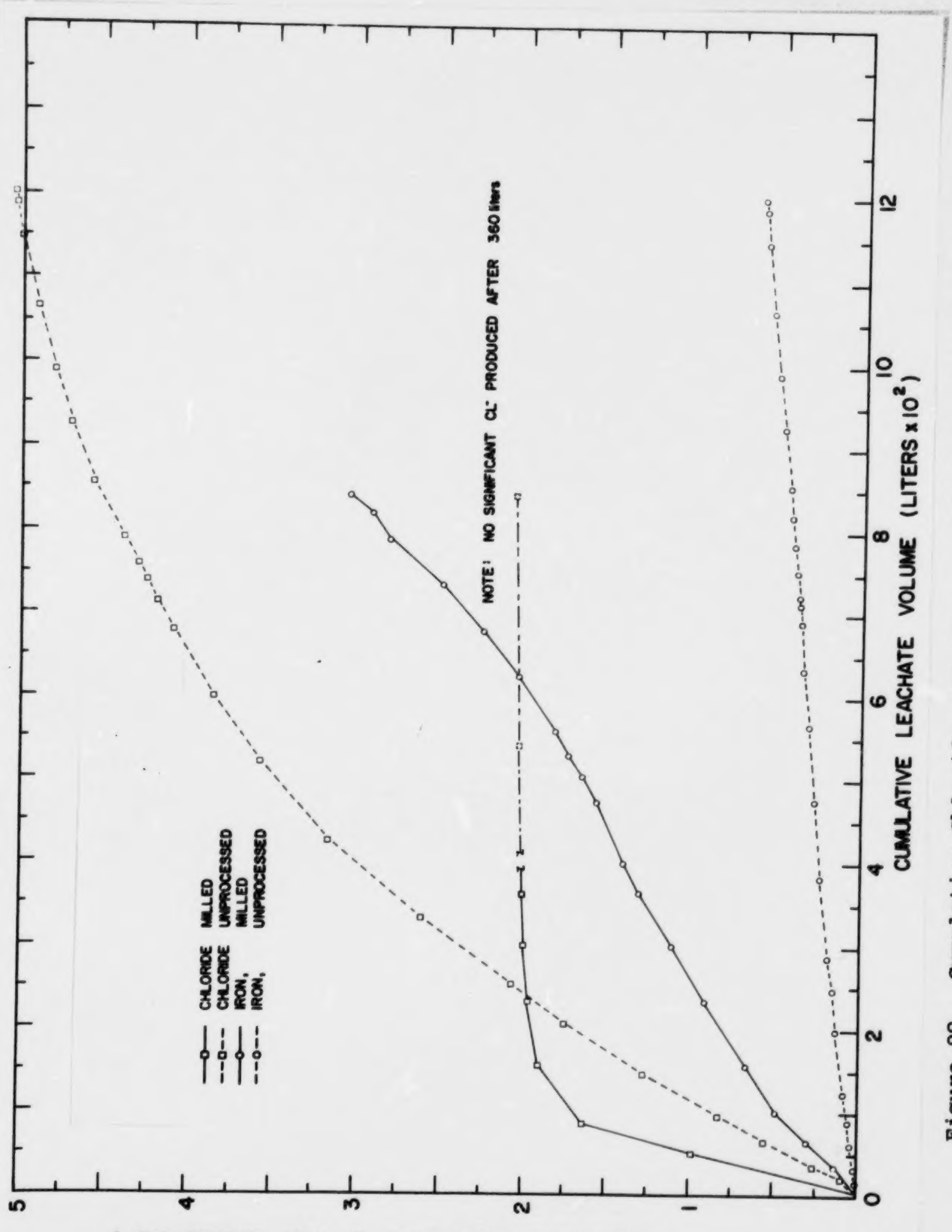

Figure 98. Cumulative Chlorides and Iron vs. Cumulative Leachate Volume

or run tangent to each other. This indicates that milled refuse releases more of the stated pollutants earlier in the degradation process than does unprocessed refuse but also that the total production of these contaminants by the two cells is similar.

The milled cell was found to produce more dissolved solids. This may be explained by the fact that milling exposes more surface area from which solids can be more quickly dissolved during leaching. The same reasoning may explain the difference in production of total hardness. The largest difference in total production was found for iron, where the milled cell produced more than five times as much as the unprocessed during the 270-day study. One reason for this could be that milling removed some of the protection originally present on iron surfaces, such as paint or other coatings.

The apparent difference in amount of chlorides cannot be used as the basis for a definite conclusion because the results for the milled cell are unreliable due to severe problems with interferences in the test. For total and ortho-phosphate, the milled cell showed a higher production and the curves were diverging at the end of the study, indicating that the difference in total production probably would have increased if the test had continued beyond the 270 days. For NH_3 -N, the production was nearly five times larger for the unprocessed than for the milled cell. For organic N, the unprocessed cell showed higher production, but the difference is too small to be significant.

The production of nitrogen and phosphous is believed to be partly dependent on bacterial activity. Some of the ammonia nitrogen found in the leachate is probably produced by bacteria, but from the large difference in total NH_3 -N alone, it cannot be concluded that there was a much higher level of bacterial activity in the unprocessed cell. No other parameters give support to a conclusion of that sort.

Examination of the total amounts of the various substances shows clearly that the amounts carried away by the leachate are very small, or almost negligible compared with the total amounts originally present in the refuse. The total amount of solids removed by leachate, for instance, was 7.495 kg (16.8 lbs.) for the milled cell, while the total dry weight of refuse was 1038 lbs. This represents a weight reduction of 1.62 percent. The total amount of iron in the leachate from the milled cell was found to be 0.320 kg (0.718 lbs.), while the initial amount in the refuse was 83.9 lbs. This represents a reduction of about 0.85 percent from the initial weight of cans and metal. There is reason to believe, therefore, that production of most of the substances would have continued for a relatively long time if the test had not been terminated. It should be kept in mind that this experiment was run under conditions that promoted rapid degradation, and hence rapid production of pollutants. Under most landfill conditions, pollutants will normally be released at a much slower rate.

Grams and Concentrations vs. Time

As stated previously, an attempt will be made in this section to illustrate how misleading contaminant concentration data alone can be when describing the total effect of leachate production.

99/100

Figures 99 and 100 show for comparison, curves of concentration and total production vs. time both for COD (a measure of the concentration of organic matter) and TDS (a measure of the inorganic concentration). Examining the concentration curves, it is evident that the milled cell has peaks ranging from 2 to 3 times as high as the unprocessed. These concentrations remain very high over some 20 percent of the leachate production time for the milled cell. By observation, it would seem that leachate from the milled cell had much more polluting potential than that from the unprocessed cell.

In contrast, examine total production vs. time. By observing the end points, one can see that in the case of COD the unprocessed cell actually produced more pollutant even though the milled cell had a peak concentration 2.5 times that of the unprocessed cell. In the case of TDS, the milled cell produced only slightly more of the pollutant even though the peak concentration was almost 3 times as great.

In all cases the unprocessed cell produced pollutants first, approximately 40 days before the milled cell. The rate of total production by the unprocessed cell is at first fairly low and then increases sharply after a few days. Note that the slope of the total production curve at any point indicates the rate of production of that particular pollutant, where rate is defined as grams/day. Note also, the initial production of small amounts of contaminants by the unprocessed cell, which are negligible in the cumulative curves.

Production in the milled cell of both COD and TDS was initially very sharp and dramatic. Once production reached approximately that of the unprocessed cell, the curve tapered off and followed nearly the same slope as the unprocessed cell. Note that the sudden increase in slope at approximately 170 days for the milled cell was due to the ponding effect. Ponding is also thought to be responsible for the fact that the latter end of the COD concentration curves in particular did not cross, as had been observed in previous experiments comparing milled and unprocessed refuse.

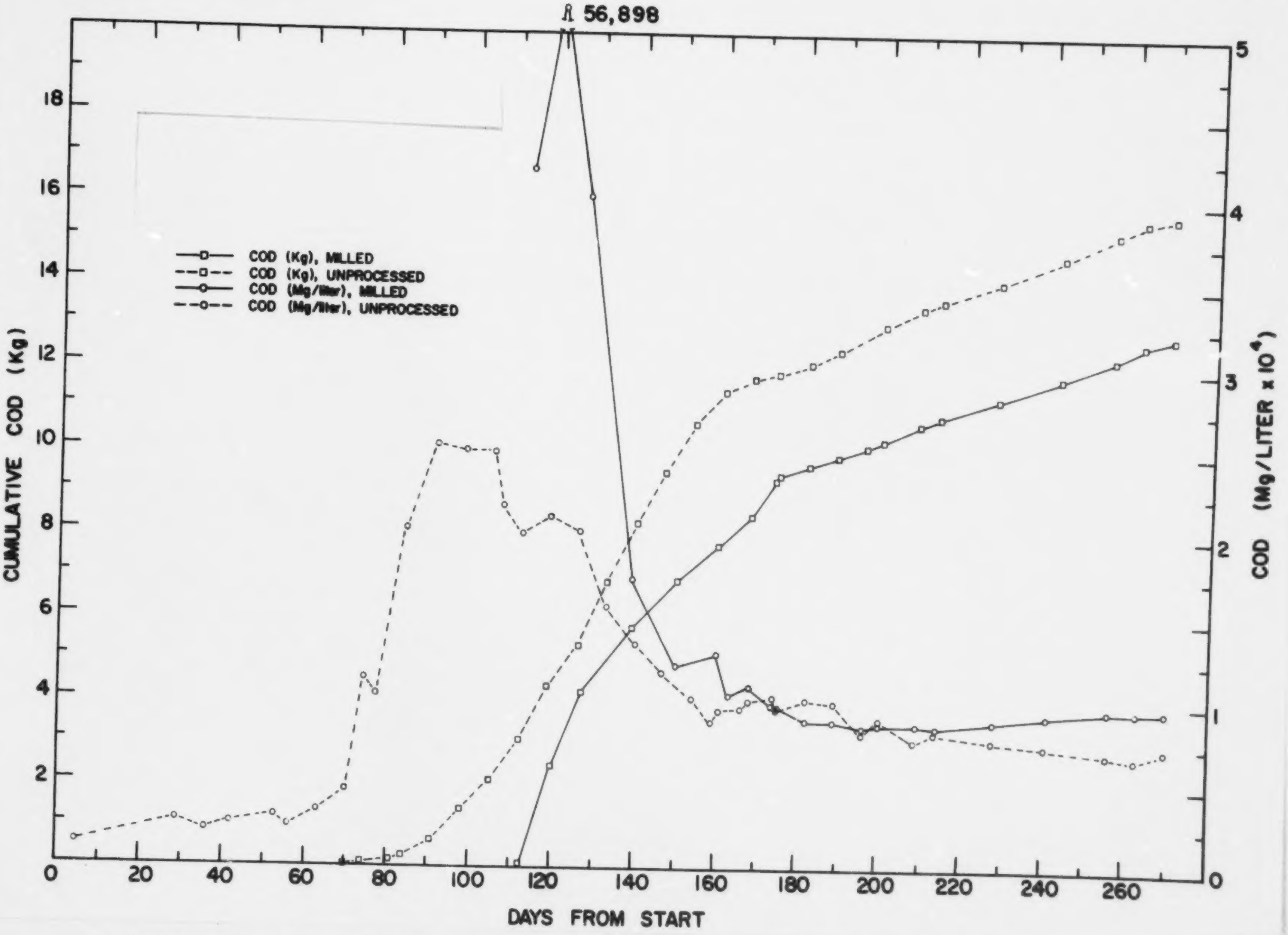

Figure 99. COD - Total Production and Concentration vs. Time

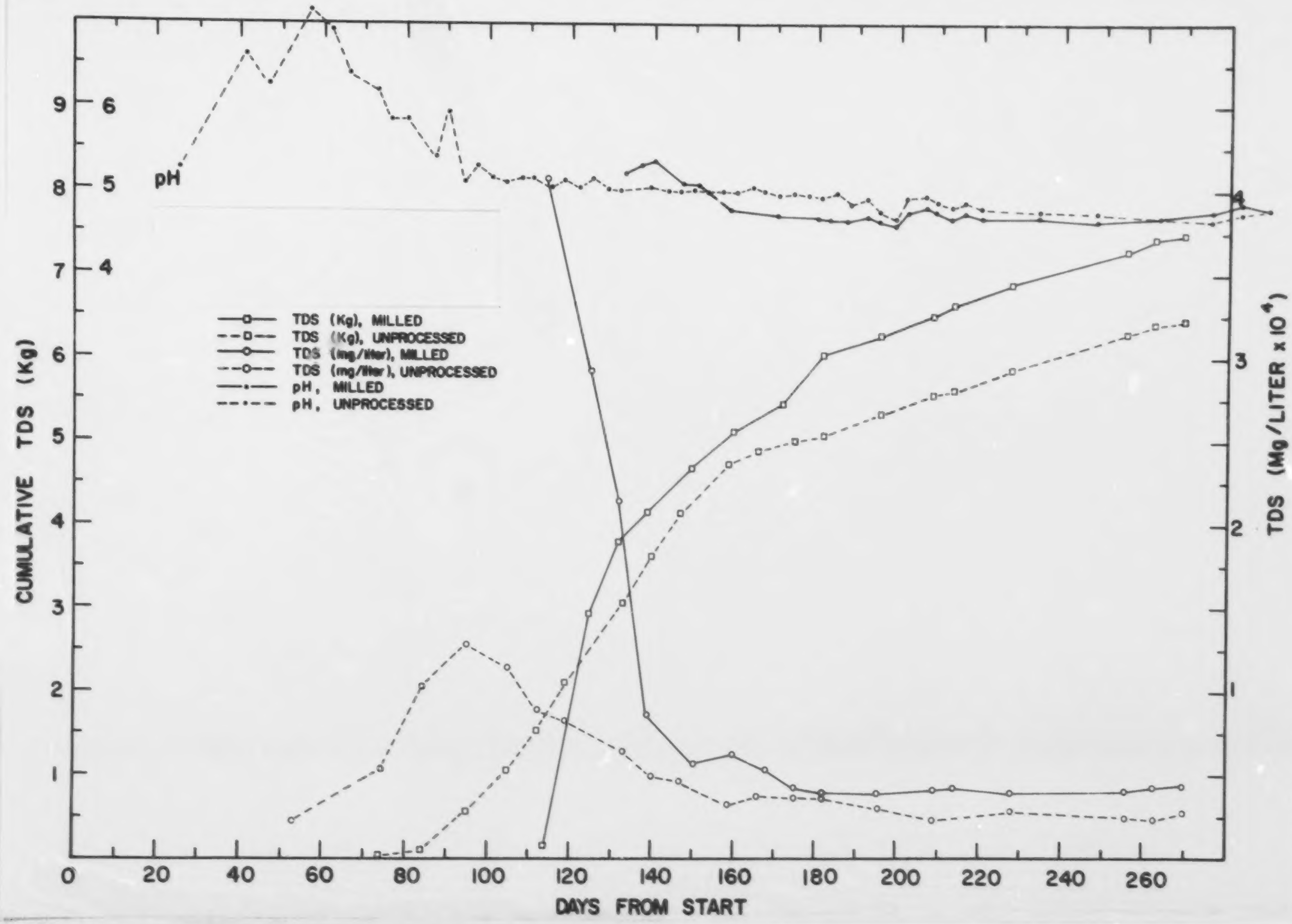

Figure 100. TDS - Total Production and Concentration vs. Time

100

pH and Conductivity

The pH for both cells, as shown in Figure 100, remained constant or was slowly decreasing throughout the study, except for some early unprocessed leachate samples where values between 6 and 7 were noted. Both cells had a pH of 5.10 to 5.30 at the time the highest production of COD occurred, decreasing to 4.60 to 4.80 toward the end of the experiment. In past work, a close relationship between iron concentration and pH in leachate has been reported. Undoubtedly, these parameters are closely related chemically, but this study tends to show that other factors might be more important for the release of iron from the refuse. The two cells exhibited nearly identical pH curves, but the iron production was much higher in the milled than in the unprocessed cell.

Tests for conductivity were also performed on leachate samples from each cell. It has been determined that conductivity is usually a good estimate of the TDS content of leachate and is often run on leachate samples in lieu of tests for TDS since it is easier and faster to complete. The conductivity and TDS curves obtained for each cell were very similar in shape; thus, the conductivity curves are not presented here. The maximum value obtained from leachate collected from the unprocessed cell was 12,500 µmho/cm, 91 days into the test. The conductivity gradually decreased to a value near 2,650 µmho/cm at the end of the study. The milled cell had a peak value of 19,000 µmho/cm, 120 days into the test. From this peak the figure dropped very rapidly to near 2,500 µmho/cm and remained relatively constant throughout the remainder of the test.

Gas Data:

The exhaust air from the rooms was analyzed for CO_2 and total hydrocarbons as CH_4. CO_2 is produced by both aerobic and anaerobic microorganisms. CH_4 is produced only under anaerobic conditions. Aerobic bacteria were probably less important in the degradation process than anaerobic, as indicated by the relatively low peak temperatures measured in the refuse.

Air flow was held constant at one cu. ft./hr. With a room volume of about 225 cu.ft., this gives an average detention time of 225 hours, or more than 9 days. Because of the long detention time and daily fluctuations in inlet air composition, it was natural to use average concentrations of CO_2 and hydrocarbons in the supply air. For CO_2 the average over the entire experiment was found to be 343 ppm. For hydrocarbons it was found most correct to compute one average for the first 80 days and another for the rest of the test period, because the first 80 days showed considerably higher concentration of CH_4 in the supply air than recorded later. The first average was 5.41 ppm based on 15 observations, varying from 3.90 to 6.45 ppm. The second average was 2.78 ppm based on 77 observations varying from 1.05 to 6.02 ppm.

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Figures 101 and 102 show concentrations of CO_2 and CH_4 vs. time. From the curves for CO_2 concentration, both cells showed peaks a few days after the start of the experiment. The milled cell peaked at 530 ppm after 2 days, while the unprocessed peaked at 550 ppm after 5 days. After the peak the milled cell had a rather rapid drop, reaching concentrations close to that of the average supply air after 50 days. After that time the concentrations stayed equal to or slightly above that of the average supply air. The unprocessed cell had a slower drop, where CO_2 concentrations stayed 50 to 100 ppm above the average up to 180 days into the study. After that no significant difference could be found between the two cells.

The recorded concentrations seem to indicate a very low CO_2 production; however, CO_2 gas is soluble in water and a large portion of it could be transported out by the leachate. The concentration of CO_2 in water can be calculated from pH and alkalinity data by use of the equation:

$$\frac{(H^+) \times (HCO_3-)}{(CO_2)} = K = 4.45 \times 10^{-7},$$

neglecting activity corrections. Knowing the concentration of CO_2 and leachate production, the amount of dissolved CO_2 becomes 2.8 cu. ft./day of CO_2 gas. The highest concentration of CO_2 in the exhaust air recorded by the CO_2 analyzer was about 250 ppm above the supply air concentration. An air flow of one cu. ft./hr. gives 24 cu. ft./day and with a concentration of 250 ppm by volume this equals:

$$24 \times 250 \times 10^{-6} = 0.006 \text{ cu. ft./day of } CO_2.$$

This calculation shows clearly that the amount of CO_2 escaping as gas was negligible compared with the amount carried by the leachate. The data obtained from the CO_2 analysis, therefore, cannot be used to calculate the total production of CO_2. It is also very unlikely that the shape of the CO_2 curve reflects the relative changes in production. The peak production of CO_2 probably occurred near the peak for the leachate parameters rather than immediately after the start of the experiment.

The hydrocarbons measured in this test are believed to be mainly methane (CH_4). This gas has very low solubility in water, consequently the gas data should give good information about the total gas production. From Figure 102, it can be seen that for the first 80 days the production of CH_4 was negligible. Between 80 and 170 days there was evidence of some CH_4 production. Exhaust air concentrations were 2 to 2.5 ppm above the supply air average of 2.78 ppm during this period. After 176 days an apparent rapid increase in methane production occurred in both cells. During

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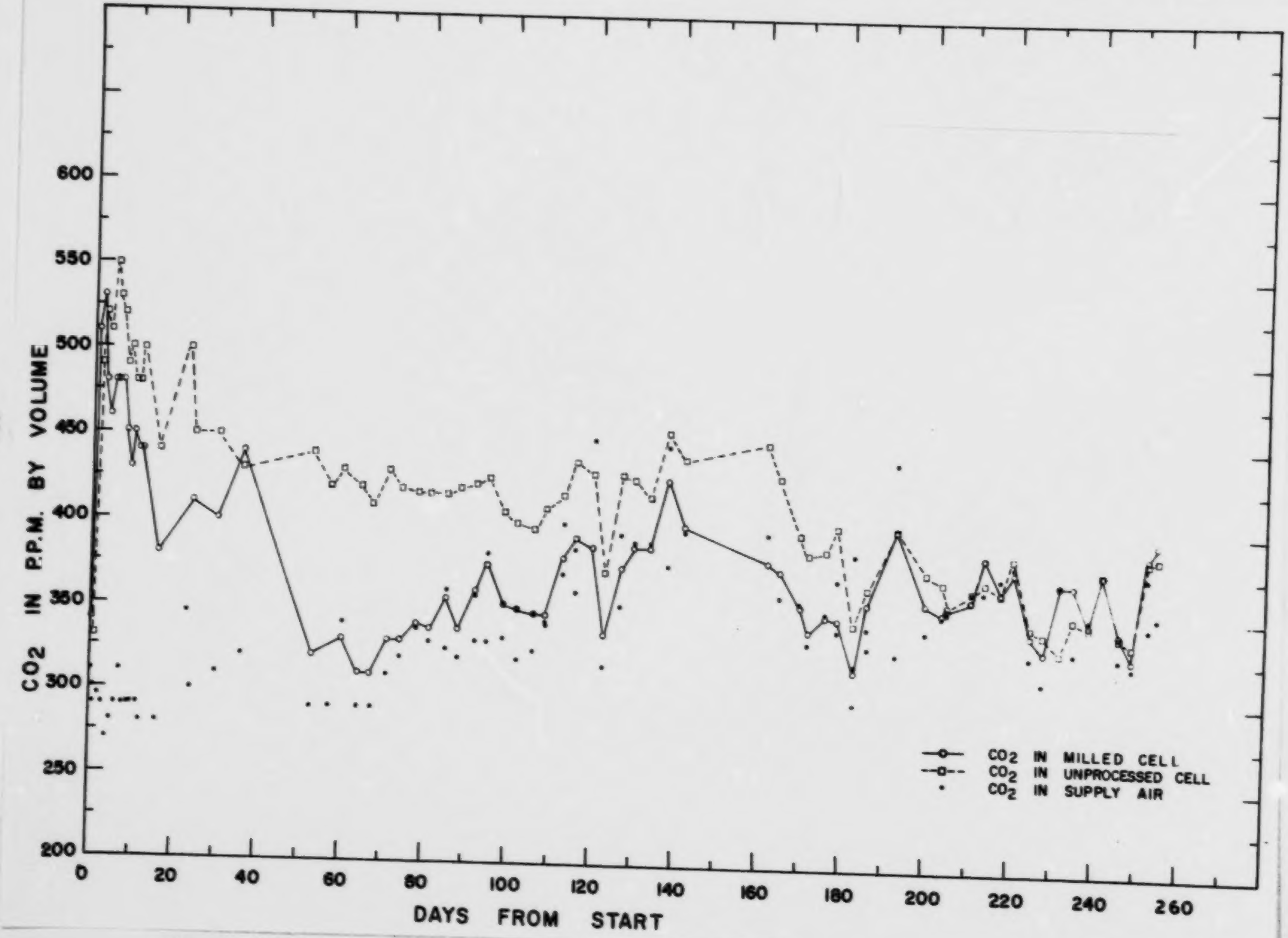

Figure 101. CO_2 Content in Supply and Air Exhaust

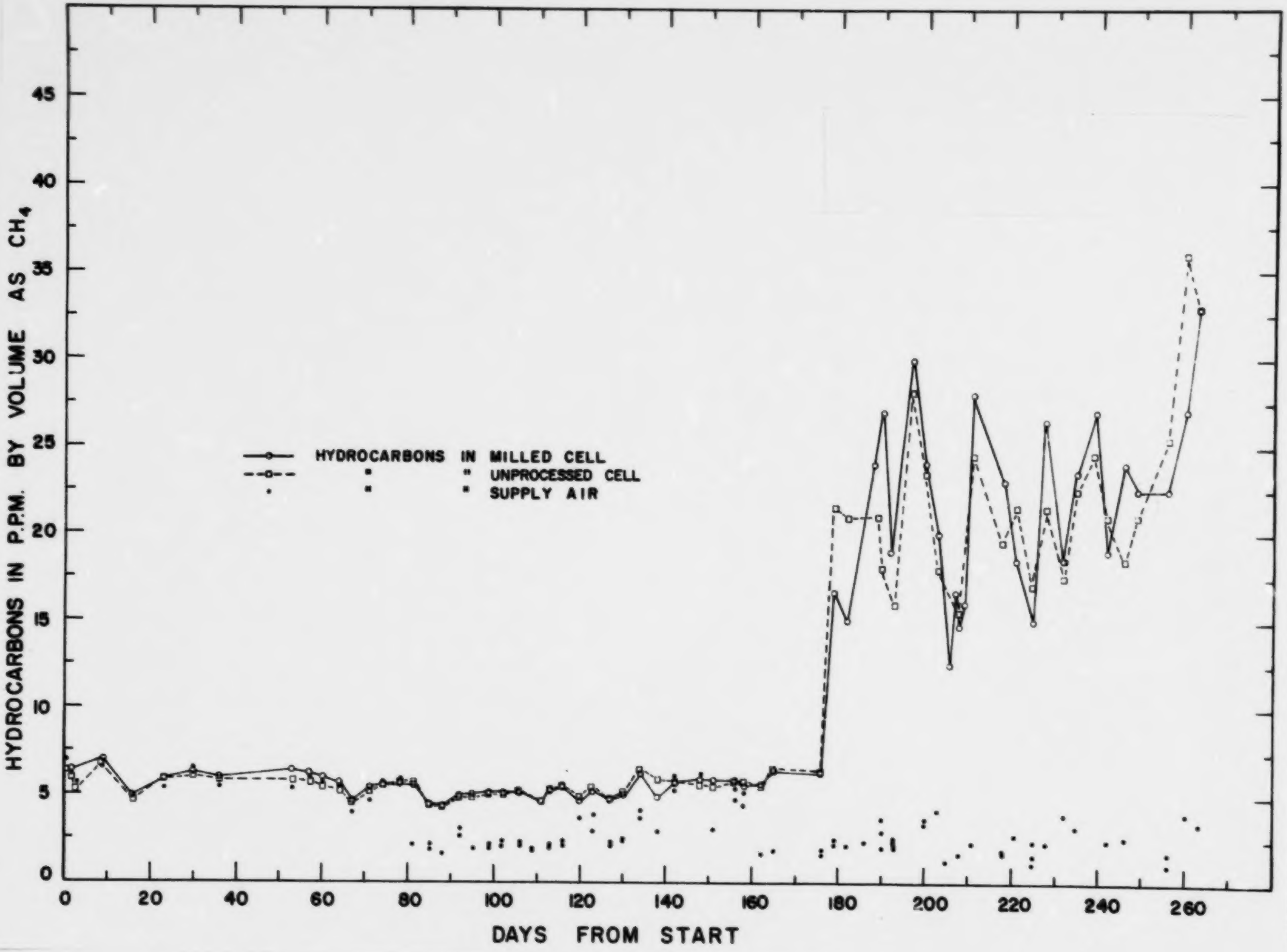

Figure 102. Total Hydrocarbon as CH_4 in Supply and Exhaust Air

the rest of the experiment, methane concentrations remained relatively high with an average of about 23 ppm for both cells. As can be seen from the graphs, the daily variations were rather large, and no significant difference could be found between the two cells. The main reason for the variation is felt to be the technique of sampling and analysis.

By calculation, the total volume of methane escaping from each cell during the 270 days' tests was 0.052 cu. ft. In light of this, it can be concluded that methane production during the experiment was almost negligible. One of the main reasons for the low methane production is felt to be the unusually low pH when compared with other degradation studies. This provides a very unsuitable environment for the methane-producing bacteria, which prefer a pH value near neutrality. It should be noted that methane production was increasing toward the end of the study and that the pH would probably have approached neutrality had the experiment continued. (See the ponding study at the end of this section for additional discussion on this matter.)

Closing Comment:

Direct use of data from this experiment has certain limitations. It must be kept in mind that the test was carried out under artificial environmental conditions and with refuse of a specific composition. In applying the data to actual landfill conditions, the effects of climatic variations, the use of cover, and different refuse composition must be considered. Also, it should be remembered that this experiment was designed to compare the early stages of decomposition, those stages thought to be of most concern from previous studies on milled refuse, so it lasted only 270 days. Reliable conclusions concerning total production of pollutants over a long period must be based on long-term evaluations.

PONDING STUDY

Description of Ponding in the Milled Refuse Cell:

Both containers used in the Biotron were designed to have free drainage of leachate; but for the milled cell this proved not to be the case. While the unprocessed cell started to produce leachate regularly after 10 weeks, the milled cell produced only very small quantities after 23 weeks. A clogging of the drain was suspected, and on July 21, the room with the milled refuse container was opened. The plastic hose connecting the container with the drainpipe was indeed clogged. This hose was replaced and the ponded leachate drained out. The cell was allowed to drain until July 28 without adding rain. In addition, the container did not prove to be completely watertight and some leachate leaked out. Since the room had no drain, the spilled leachate, minus evaporation, remained on the floor. This leachate was collected and the volume determined.

The incident made it more difficult to provide direct comparisons between the two cells as originally desired. It was important, therefore, to back calculate or reconstruct some of the data lost because of ponding. Essential in this respect was: (a) calculation of total volume of leachate that had leaked out of the container; (b) estimation of the starting date for leachate production had the drain been open; (c) estimation of leachate composition had the drain been open; and (d) determination of the effects of ponding on the decomposition process both during and after the actual ponding period.

Existing data could be used for the first three points. To solve the fourth question, a small scale degradation study was set up. This study will be discussed in detail later in this section.

(a) Obviously some evaporation had taken place while the leachate covered the floor. The following data was used to calculate the evaporation loss: total volume of leachate collected from the floor, the results from the analysis of this leachate, and the results from the analysis of three samples obtained through the clogged drain before July 21. The calculation also had to be based on two basic assumptions. First, the change in the values for conductivity, TDS, Ca-hardness, chlorides, and iron was due to a more concentrated leachate because of evaporation. Second, the average values computed from the analyses of the three early samples were close to the correct initial values for the spilled leachate. The fact that pH for the spilled leachate was close to the values found in the three early samples adds validity to the assumptions.

With the two stated assumptions in mind the average concentration factor due to evaporation was calculated to be 2.51. Knowing the volume of leachate collected from the floor to be 53 liters, an estimate of the total spillage is 2.51 x 53 = 133 liters.

(b) Back calculation of the starting date for leachate production was based on the volume of leachate drained from the cell after the drainpipe was repaired plus the estimated volume of spillage. Also used were the average evaporation rate and the volume of rain supplied. The estimated date of the starting date of leachate production corresponding to rainfall was May 28.

An estimate of the same starting date could be obtained from the moisture probe data. As described previously, the moisture front reached the bottom level probes on May 17. These probes were located three inches above the bottom of the refuse bed. The moisture front moved downward with an average speed of 3.5 in./wk. The moisture front could, therefore, be expected to reach the bottom on May 23 or 24.

(c) The analyses of the three small leachate samples obtained while the drain was clogged were used to estimate the results that would have been obtained had the cell been free draining and started leachate production on May 28. The time sequence for the early leachate data had to be changed so that results from the period between July 1 and July 23 were used for the period between May 28 and July 2. The total amount of leachate produced up to July 23 was then portioned out according to the new time scale. It cannot be claimed that the results for the period between May 28 and July 2 give a correct picture of what would have happened without the clogging, but the results are valid as average values for the leachate produced during this period.

(d) From visual evidence outside the container it was estimated that the leachate had built up 34 in. above the bottom of the refuse, where the top 24 in. of refuse remained above the water at maximum ponding. This ponding probably had an influence on the biological activity in the cell, thereby affecting the release of pollutants, gas production, etc. There was also a possibility that this ponding could affect the behavior of the cell even after it had been drained. This problem was examined in a special study.

Small-scale Experiments to Study Effects of Ponding on Refuse Decomposition:

The equipment used for this study consisted of two plastic bottles from which the bottoms had been removed. The total volume of each was 16 l. The bottles were placed upside down and equipped with a drainpipe from the bottleneck and a plastic screen near the bottom.

The containers were filled by hand with milled refuse from the Olin Avenue milling plant. For each container the volume of refuse was 14.8 l and the total refuse weight was 4.30 kg. This gave an in-place density of 489 lbs./cu. yd. The initial moisture content was determined to be 44.5 percent based on dry weight.

The containers were placed in an incubator which was set at a temperature of 32° C. The refuse surface was covered with a plastic sheet to minimize evaporation. One container was filled with 10 l distilled water and the drainpipe was kept closed. The other container had free drainage throughout the experiment, and no initial water was added. Both containers were supplied with 500 ml distilled water twice a week. The water was distributed evenly over the surface by use of a can with a perforated bottom. In order to keep the water level constant in the ponded cell, leachate was taken out in amounts equal to the amount of water added.

Since the experiment was started on August 12, the refuse composition was different from that used in the Biotron experiment.

In particular there would be more greens in this sample. This fact, and the difference in density and environment, exclude any direct comparison of the results from this pilot study with those obtained from the Biotron experiment. However, it was the relative behavior of the two cells that was of main interest.

The pilot study was run with one ponded and one drained container from August 12 to September 27, or 46 days. After September 27, both cells were run with free drainage. The test was terminated after 88 days. The total amount of distilled water supplied was 21,500 ml for the ponded cell and 12,000 ml for the drained. The total amount of leachate collected from the ponded and drained cell was 15,640 ml and 7,399 ml, respectively.

A less extensive program of analysis was performed in this experiment than in the main study. The emphasis was put on the leachate analysis where only the most important and most characteristic parameters were selected. The following tests were run on the leachate: pH, conductivity, COD, total hardness, Ca-hardness, chlorides, and solids. In addition, the volume of leachate was measured. The same procedures were used as in the main experiment, except that settling time before decanting was reduced from 4 hrs. to 1 hr. In addition to the leachate analysis, the temperature in the room and within the refuse (as measured by a glass thermometer imbedded in the refuse) was recorded.

Results From the Study: 103 104

Cumulative amounts of pollutants produced vs. leachate volume are shown in Figures 103and 104. Except for chlorides, the two cells produced nearly equal amounts of pollutants for equal amounts of leachate until the ponded cell was drained. At this point the two curves diverge, with the ponded cell producing at a relatively constant rate and the drained cell at a decreasing rate. This is hard to explain, but it is safe to assume the difference is due to the ponding effect. Lower pH in the ponded cell could be one reason why pollutants were more readily released from that refuse; but whether the difference in pH for the two cells was due to the ponding or other factors cannot be fully evaluated from this experiment.

105 106 107

Graphs of the tested parameters with respect to concentration are shown in Figures 105, 106, and 107. These curves also illustrate the ponding effect quite remarkably. The drained cell curves exhibit a shape comparable to other curves obtained during previous degradation studies. Peak values are seen relatively soon in the test followed by a pronounced and then more gradual decline in concentrations. The ponded cell exhibits no such change but seems to have a curve maintaining almost constant and relatively high concentrations. The slight decline that did occur in concentrations happened after the cell was drained.

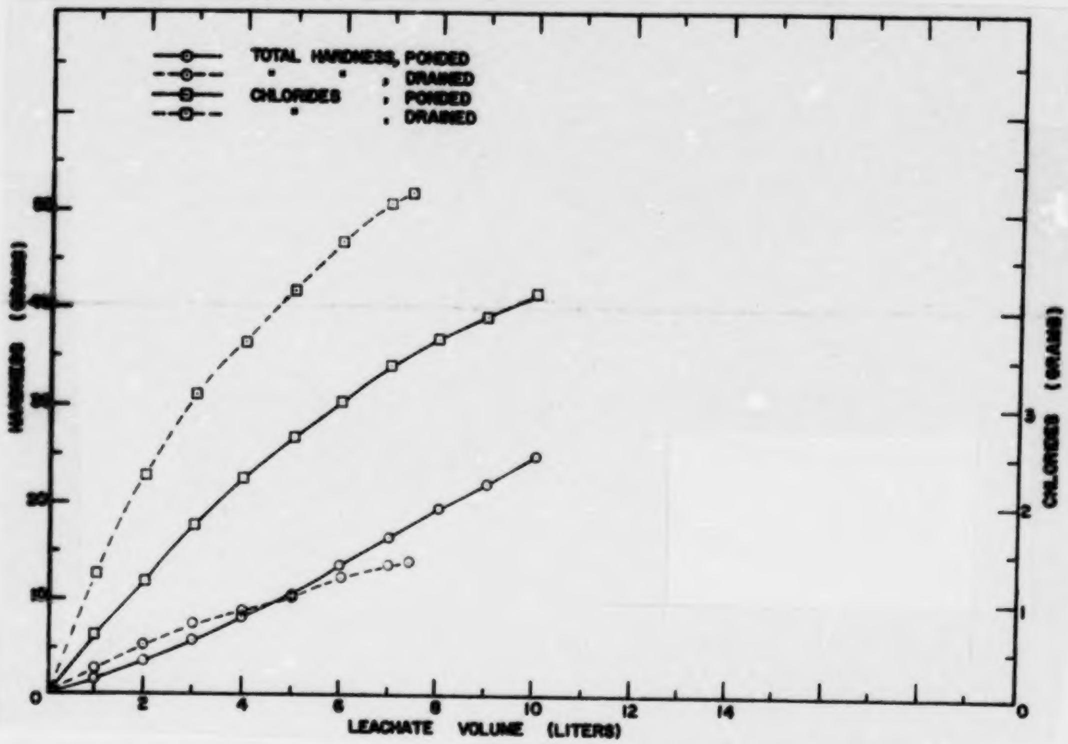

Figure 103. Cumulative Hardness and Chlorides vs. Volume

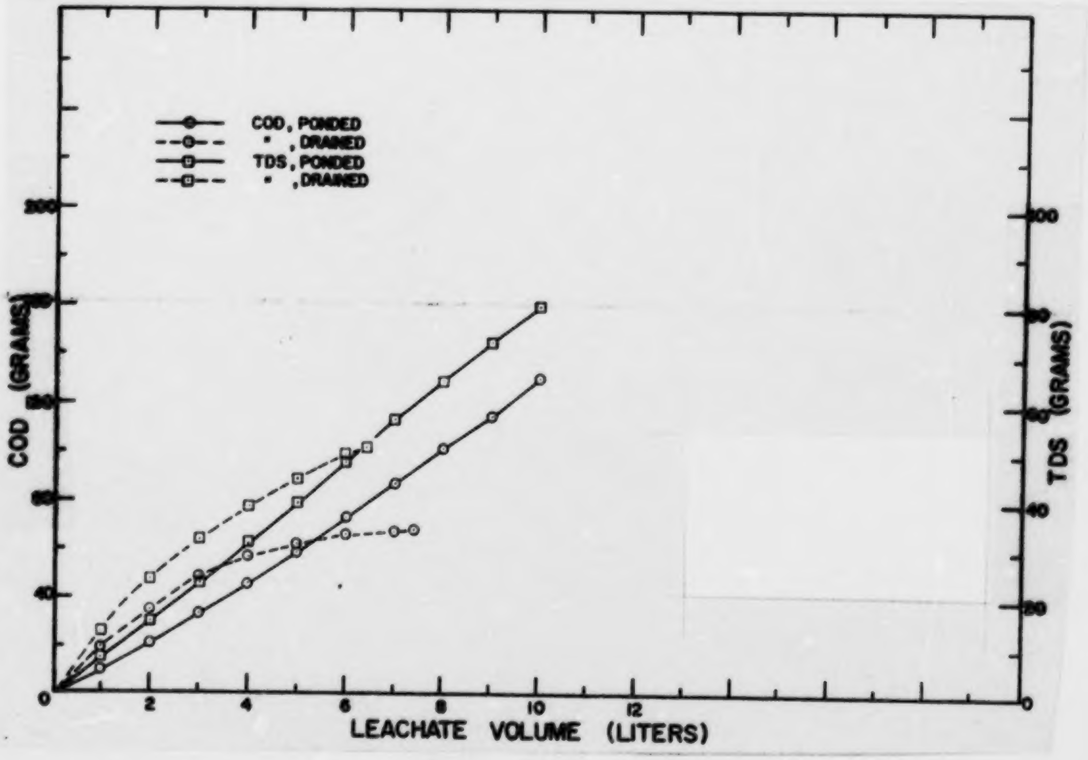

Figure 104. Cumulative COD and TDS vs. Volume

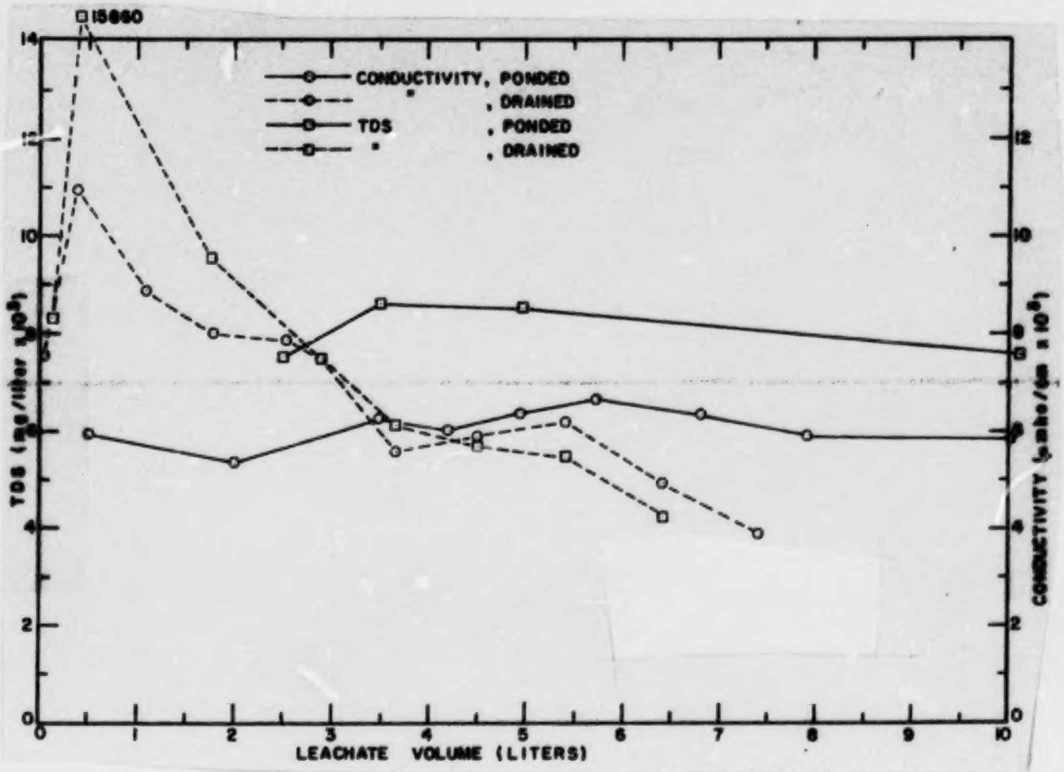

Figure 105. Conductivity and TDS vs. Volume

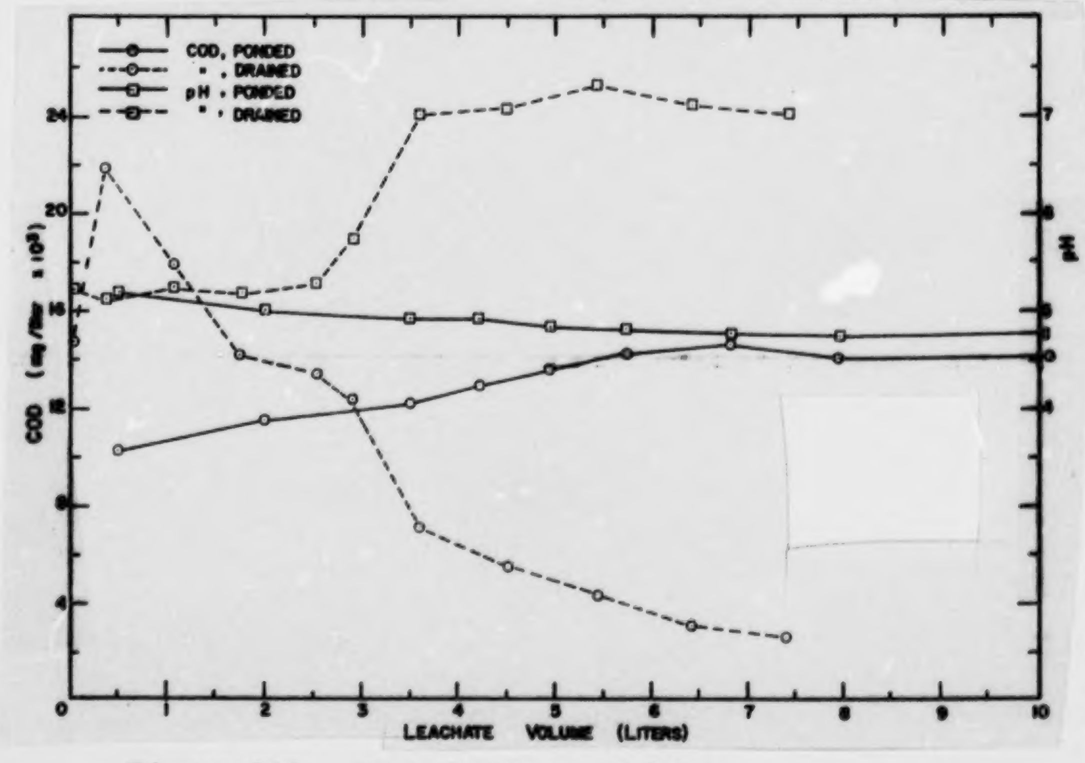

Figure 106. pH and COD vs. Volume

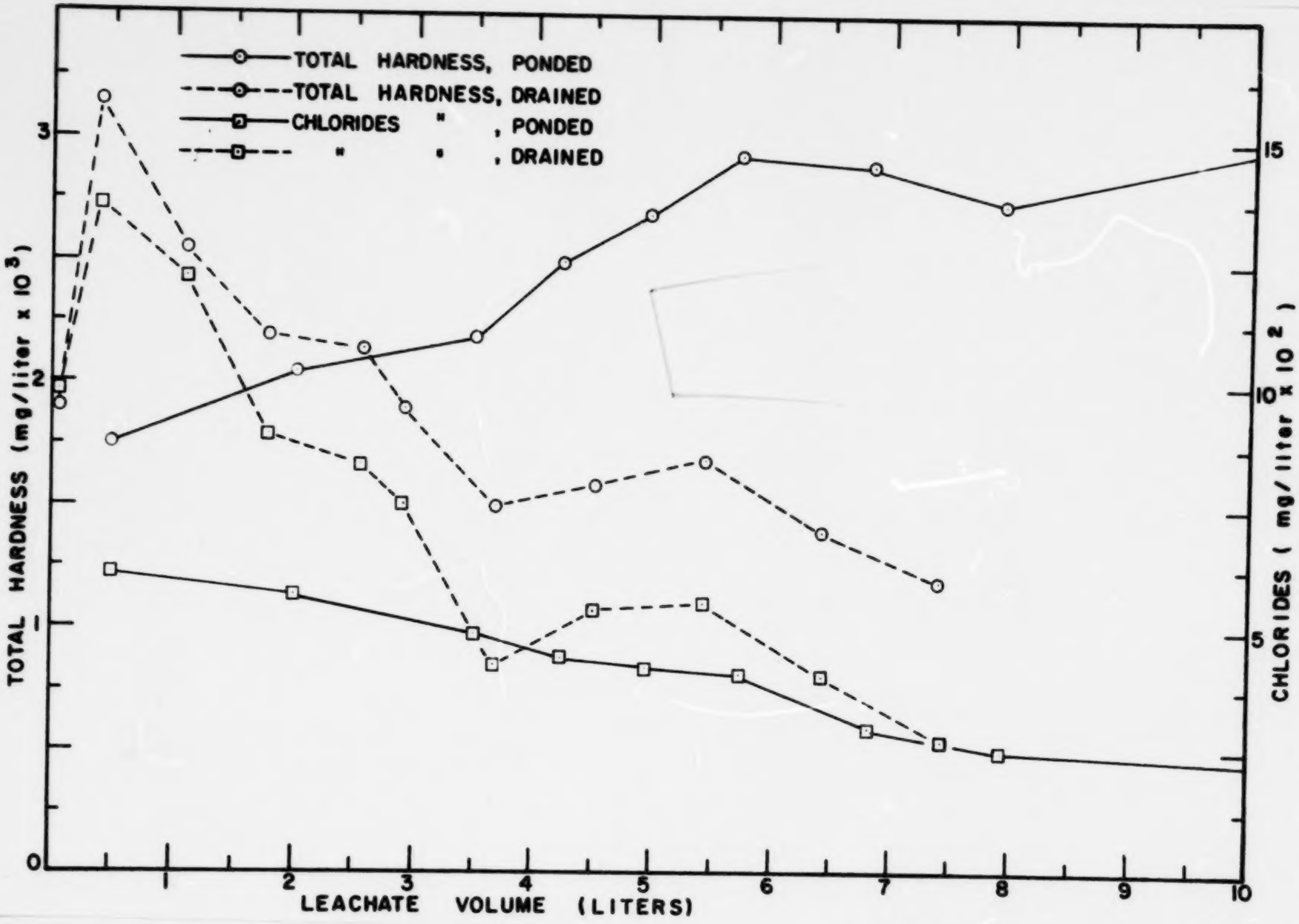

Figure 107. Total Hardness and Chlorides vs. Volume

The difference in pH for the two cells is striking. The ponded cell had a pH of 5.20 at the start, but this declined through the experiment to 4.80. pH for the drained cell also started at 5.20, and stayed about constant for 4 weeks. Then, there was a rapid rise in pH value during the next 2 weeks from 5.27 to 7.00. This change coincided with the second rapid drop for the other parameters. The simultaneous change in pH and COD may indicate a change in the type of bacteria from producers of organic acids to methane producing bacteria. pH for this cell remained slightly above neutral during the rest of the study.

It is clear from this study that ponding in the milled cell in the Biotron changed the results, somewhat, from what they would have been. Furthermore, this study shows that the total amount of pollutants produced over a longer period will be increased by ponding. Consequently, the calculated total amounts for the milled cell in the Biotron are probably larger than what would have been found in a situation with free drainage. Also, the study showed that ponding tends to depress peak concentrations, but in contrast, concentrations will remain relatively high for a longer period of time than in a comparable drained situation. Finally, the gradual increase in pH of the drained cell to a value of 7.0 suggests that ponding reduced the rate of methane production in the milled Biotron cell.

VIC-29

VII. TREE GROWTH AND OTHER VEGETATION ON REFUSE

TREES

INTRODUCTION

A study was initiated to determine the ability of milled refuse to support tree and shrub growth. It was performed in conjunction with the Olin Avenue refuse milling and landfill operations of the City of Madison.

The amount of published information on this subject is minimal. Several instances of problems in plant growth on landfills were described in a report in "The American City" (1965). It cited a problem caused by gas which killed several trees on a five-year-old site in Elmhurst, Illinois. At a golf course constructed on a newly completed landfill in Savannah, Georgia, only six pine trees survived out of 200. It was found that only those trees with a thick blanket of soil between the roots and the refuse had remained alive. It was also found that there were differences in tolerance to landfill conditions among several varieties of Bermuda grass. D.K. Holland, Director of Public Works in Kenosha, Wisconsin, wrote of substantial difficulty encountered in growing trees, shrubs, and grass in parks established on sanitary landfills (personal communication). He attributed the problem either to gases being expelled from the refuse or to lack of an adequate soil base over the fill. Such instances point to the need for research on what causes such problems and what can be done to alleviate them.

OBJECTIVES

This project was designed to determine the soil properties and species which could be used to achieve successful establishment and growth of trees and shrubs. The type and thickness of soil material covering the refuse as well as tree and shrub species were varied to determine which combinations gave the best growth. Ten species of seedlings were grown to see if any had an advantage under landfill conditions. Experimental plots were established on both milled and unprocessed refuse to determine if there were any differences in growth due to the composition of the underlying refuse. Additional plots were established to determine the effects of fertilizer on the growth of trees on the landfill.

The method of application of the soil cap produced some modification of the original objectives. The soil cover is often compacted to slow decomposition of the underlying refuse and to reduce infiltration. In this case, however, the extensive grading necessary to obtain desired soil depths so compacted the soil that the roots did not achieve appreciable penetration and have therefore not yet (September 1972) entered the refuse as originally planned. As a result, the full effect of the underlying refuse on tree growth has not been completely determined. Although gas evolving from the refuse diffuses through the soil, the composition of the soil air differs from that in the refuse. Had the roots entered the refuse, they would have encountered an environment which likely would have been very poor for plant growth.

EXPERIMENTAL DESIGN

The study consisted of two major blocks; one on unprocessed refuse and one on milled refuse. The blocks were laid out and surveyed to set up the depths of soil cover desired. Since milled refuse does not require a soil cap, the cover material was applied solely to improve the conditions for tree growth. The additional cover on the unprocessed site was also applied to determine the effects of depth of soil cover on tree growth. The soil material was trucked in and spread to the prescribed grade with a bulldozer. In the application and grading of the fill to its prescribed depths, the soil cap was compacted greatly.

The soil material and the soil thickness were varied on the two blocks as follows: Each block was divided into 6 x 30 meter plots. The plots were separated by 3-meter buffer strips which were planted to grass. Three of the plots in each block were covered entirely with subsoil--one to a depth of 15 cm., one to 30 cm., and the other to 45 cm. The other three plots in each block had the three depths of subsoil plus a 15 cm layer of topsoil applied above the subsoil. The fertility plots had only 15 cm. of subsoil applied to the milled refuse.

During application of the soil materials, actual thicknesses achieved varied significantly from the prescribed thicknesses. Because of this, the depths which are referred to in the experiment are only approximate.

Ten species of plants were planted in the experiment:

White ash	*Fraxinus americana*
Ninebark	*Physocarpus maxim*
Gray dogwood	*Cornus racemosa*
Silky dogwood	*Cornus obliqua*
Wayfaring tree	*Viburnum lantana*
Buffaloberry	*Shepherdia argentea*
Russian olive	*Elaeagnus augustifolia*
Red pine	*Pinus resinosa*
Jack pine	*Pinus banksiana*
Crab	*Malus* spp.

For simplicity, all plants will be referred to as trees in the following discussion.

Ten trees of each species were planted in each plot. Trees were planted four feet apart in rows of five of one species. Rows were placed five feet apart. Each row of five trees was randomly located within each half of the plot. The block on the milled refuse was planted on May 25, 1970; that on the unprocessed refuse was planted June 10, 1970.

A supplemental experiment consisted of 50 each of jack pine, red pine, and white ash trees in separate plots on the milled refuse to evaluate effects of fertilizer on tree establishment and growth. The trees were spaced as above in plots 6 x 15 meters. Fertilization was done using one ounce polyethylene packets in varying quantities. The four randomized treatments were: 1) check (no fertilizer), 2) four packets, 3) loose fertilizer from two packets, and 4) loose fertilizer from two packets plus four intact packets. The fertilizer was applied 15 cm deep in the soil in a 15 cm radius circle around each tree two weeks after planting.

Additional trees, which were not originally planted, were healed in and were used to replace the dead trees on all of the plots on July 21, 1970. During the first summer (1970), the plots were watered four times for a total of less than half a hectare cm. There was no further irrigation after the first summer. During the first two summers of growth, weeds were controlled by mowing. Weeds near trees were also controlled to some extent through the use of Amitrol-T, applied at a rate of 3 liters per hectare. It also became necessary to spray the trees with a repellent to protect them from rabbit damage in the winter of 1970-71. A recording rain gauge was installed at the landfill and records of precipitation were kept from August 1970 through November 1971.

Plant Evaluation:

The trees were periodically checked to determine mortality, vigor, and growth. Records of the trees' condition were kept along with periodic height and diameter measurements. Because of the bushy type of growth of many of the trees (crab, ninebark, Russian olive, buffaloberry), height and diameter were difficult to determine. This made it necessary to mark the leading shoots so that the same ones could be measured each time. Marks were also made on the shoots approximately 7 cm. from the soil surface so that diameter measurements could be taken at the same point each time.

A total of 43 samples for foliar analysis were taken; the samples represented three species (jack pine, red pine, and white ash) and included milled and reprocessed blocks, several fertility plots, and reference sites.

The white ash tissue samples were analyzed for N, P, K, Ca, Mg, Al, Ba, Fe, Sr, B, Cu, Zn, Mn, and Cr. Jack pine and red pine samples were analyzed for N, P, Ca, and Mg. All tissue analyses were performed by the Wisconsin State Soil and Plant Analysis Laboratory.

Soil Evaluation:

Physical Analyses

Tensionmeter measurements to determine soil water potentials were taken on the milled site from July through October, 1971. Eight tensiometers were placed in four areas on the milled site at depths of 12.5, 27.5, and 42.5 cm. Measurements were taken at intervals of two to three days throughout the period. Soil bulk density was determined at several locations on both the milled and unprocessed sites using an excavation method. Soil texture was determined on several samples taken at various locations on both the milled and unmilled sites using the Bouyoucos hydrometer method.

Determination of hydraulic conductivity was made on soil cores obtained with a Uhland sampler.

For determination of moisture retention curves encompassing high as well as low values, samples with field structure were used. Bulk densities were determined using these volumes and the dry weights of the uncoated clods. Particle density of the clods was determined using a glass pycnometer. Porosity was calculated using bulk density and particle density.

Gas samples were taken from the soil four times from May to August, 1972. Ten 5-cm.-wide pipes with four small holes near the end were driven into the soil after a smaller soil core had been removed to aid in the driving. They were placed in four areas on the milled site at depths of 15 cm. and 30 cm., and at 7 cm., above the refuse surface. The pipes were capped tightly on top with rubber stoppers fitted with Tygon tubing. Gas samples were taken by the following procedure: The tubing leading from the pipes was attached to a vacuum pump which pulled the soil atmosphere through a glass cylinder equipped with a stopcock at both ends. The cylinder was first emptied of air by pumping while only the stopcock nearest the pump was open. The other stopcock was then opened and soil gas drawn through the cylinder for 15 seconds at 0.35 kg./cm.^{2} suction. The stopcock nearest the pump was then closed and the gas in the cylinder allowed to reach equilibrium with the gas in the pipe for an additional 15 seconds. The stopcock leading to the soil pipe was then shut and the gas in the cylinder retained for analysis. The samples were analyzed for carbon dioxide, oxygen, nitrogen, and methane on a gas chromatograph.

To determine the degree of soil compaction and ease of root penetration, measurements were taken with a pocket penetrometer. Readings were taken at several depths in two separate profiles in the landfill, and under pine and birch stands in the University of Wisconsin Arboretum for comparison with landfill values. In total, two landfill profiles and two Arboretum profiles were sampled at three different depths which varied with the profile. Nine determinations were made at each depth.

Soil temperatures were recorded at intervals from January to June 1972 using diodes. Fourteen diodes were placed in seven areas on the milled site at depths of 7, 15, 30, and 41 cm.; the 41 cm. depth diode was 2 cm. above the refuse surface.

Chemical Analyses

Composite soil samples were taken for chemical analysis in July 1970. Samples were analyzed for total N, available P and K, exchangeable Ca and Mg, organic matter content, and pH by standard methods.

RESULTS AND DISCUSSION

Plant Evaluation:

Tree Growth

Growth measurements were taken on all ten species planted, but only white ash, jack pine, red pine, and buffaloberry were selected for representative analyses of growth (Tables 61 and62). Although one year (November 1970 to September 1971) is a rather short period upon which to base conclusions (it often takes longer to increase a tree's photosynthetic capability), some differences in growth were found in this time. On spoil sites, it has often been found that few growth differences occur after two years in spite of highly variable site conditions. In this study, however, soil type was found to be a significant factor in producing growth differences in a single year. Most of the species other than jack pine increased in height and diameter more on topsoil than subsoil. This is reasonable because the low fertility of the subsoil was likely adequate for the low-demanding jack pine. White ash and buffaloberry had much greater growth than red and jack pine. This is to be expected since white ash is normally quickly established, while the pines, expecially red pine, are slowly established. White ash is also much better adapted to dense soils than red and jack pines. It was noted that the condition of the planting stock used in this study had little influence on the growth achieved. For example, the buffaloberry stock which had been stored for two weeks prior to planting produced greater growth than seedlings which were planted in "optimum" condition.

Tree Survival

Many of the planted trees (19 percent) died the first year of the study (Table 63). The losses were attributed to establishment shock, poor planting stock, and poor planting conditions. The unprocessed block was planted two weeks later than the milled block, when the soil was very dry. Such dry conditions are very poor for tree establishment. The delay in planting also caused a great deterioration of the planting stock. These two factors, then, contributed to the much greater initial mortality on the unprocessed site as compared to the milled site.

Much greater initial mortality occurred on the unprocessed topsoil block than on the unprocessed subsoil block; this difference can be partially explained by the greater weed competition on topsoil than subsoil. The greater week growth on topsoil on both blocks was due to a greater carry over of weed seeds in the topsoil than in the subsoil. This is one problem which must be dealt with if topsoil is used for tree planting.

TABLE 61

Percent Growth Increase* Of Various Plots

Plot**		White Ash		Red Pine		Jack Pine		Buff
		Ht.	Diam.	Ht.	Diam.	Ht.	Diam.	Diam.
Milled	(A)	--	--	2. 8	8. 0	29. 3	19. 7	32. 6
"	(B)	43. 0	51. 3	2. 8	3. 5	41. 6	34. 2	27. 5
"	(C)	23. 5	28. 4	1. 6	10. 6	12. 8	9. 4	6. 7
"	(D)	53. 7	61. 5	11. 1	19. 6	--	--	30. 2
"	(E)	48. 4	47. 6	14. 8	13. 6	19. 0	4. 7	33. 5
"	(F)	50. 5	70. 4	18. 9	20. 6	25. 8	17. 8	35. 6
Unprocessed	(A)	27. 6	15. 1	9. 9	5. 5	6. 6	7. 6	57. 6
"	(B)	61. 7	38. 2	10. 1	13. 0	11. 1	18. 8	55. 6
"	(C)	93. 8	54. 9	11. 2	8. 8	12. 9	14. 6	67. 8
"	(D)	71. 1	69. 2	13. 0	27. 2	29. 1	10. 6	39. 2
"	(E)	41. 7	71. 4	--	38. 0	24. 6	16. 7	87. 7
"	(F)	19. 7	24. 6	--	9. 0	17. 3	15. 1	12. 3

*From November 1970 to September 1971.

**Plot A - 15 cm subsoil
B - 30 cm subsoil
C - 45 cm subsoil
D - 45 cm subsoil beneath 15 cm topsoil
E - 30 cm subsoil beneath 15 cm topsoil
F - 15 cm subsoil beneath 15 cm topsoil

TABLE 62

Percent Growth Increase* On Basis Of Various Factors

			White Ash		Red Pine		Jack Pine		B. Berry
			Ht.	Diam.	Ht.	Diam.	Ht.	Diam.	Diam.
Block	Milled	(M)	45	52	9	15	29	21	31
	Unprocessed	(U)	55	45	11	14	17	14	57
Soil Type	Subsoil	(S)	50	38	7	9	19	18	47
	Topsoil	(T)	48	57	14	21	23	14	39
Block X Soil Type	Milled, Subsoil		33	40	2	8	31	24	27
	Unprocessed, Subsoil		62	37	10	9	10	14	60
	Milled, Topsoil		51	60	15	20	23	12	33
	Unprocessed, Topsoil		45	54	13	24	23	14	52
Depth of Soil	15 cm		49	49	9	15	21	12	39
	30 cm		49	51	10	14	25	21	49
	45 cm		50	45	12	14	16	14	41
Subunit**	1		50	52	11	16	20	14	42
	2		49	45	9	13	22	18	44

*From November 1970 to September 1971.

**Subunit 1 - east half of plot
2 - west half of plot

TABLE 63

Percent Tree Survival On Basis Of Various Factors

	November 1970	July 1971	July 1972
Milled	92	77	25
Unprocessed	71	77	45
Subsoil	89	74	36
Topsoil	74	70	34
Plot* A	87	76	29
B	89	72	42
C	90	74	37
D	82	80	43
E	70	33	28
F	68	62	30
Milled, Subsoil	93	66	17
Milled, Topsoil	92	87	34
Unprocessed Subsoil	86	82	55
Unprocessed Topsoil	56	52	45
Total	81	72	45

*From November 1970 to September 1971.

Severe desiccation of many of the trees was noted during the first year. The dry conditions the first year made it necessary to irrigate both blocks to prevent much greater mortality. Although only 1/2 cm. hectare (1/2 acre-inch) of water was applied in total, some irrigation was necessary. Because of the very poor initial survival, many of the trees were replaced approximately a month after the original planting dates. The survival data do not take into account the fact that many trees were replanted.

Studies of plant growth on spoil banks have indicated that most tree mortality occurs the first year after planting, with very small increases in mortality occurring in later years. The results of this study disagree with this trend. Little additional mortality did occur on either site until the fall and winter of 1971-72 when a rapid upsurge in mortality (65 percent in total) occurred; this was attributed to a lack of adequate soil aeration, as will be discussed later. One of the reasons for such a hypothesis is that all species survived better as of 1972 on topsoil on the milled site while all species did better on subsoil on the unprocessed site. A likely reason for the much better survival on topsoil on the milled site is that the topsoil had an additional 15 cm. of soil cover as compared to the subsoil. This extra soil acted as a buffer between the tree roots and the gases produced by the decomposing refuse. Since the trees also had better survival on the unprocessed than the milled site, it was also hypothesized that gas production by milled refuse was greater than for unprocessed refuse. All species except jack pine had better overall survival on the unprocessed than on the milled site; poor initial survival of jack pine on the unprocessed site accounts for this discrepancy (Table 64). In addition, white ash and crab had very much better total survival than the other species as of 1972.

Root System Evaluation

Any limitation in root growth and/or function will hinder the uptake of water and nutrients, and overall tree growth will be adversely affected. Soil levels of water and nutrients which would normally be adequate for tree growth may be so poorly utilized by the tree roots that deficiencies appear. The process of root extension may significantly increase the water and nutrients which come in contact with the roots. The ability of a tree to grow adequately in later years is dependent upon the root framework established the first few years following planting. Therefore, the extent of rooting in the first years of growth will determine the growth which can be expected in later years.

Root growth and function are dependent on several factors. The genetic character of the tree will partially determine the final root form which is produced. Silky and gray dogwood illustrated this by achieving the greatest vertical penetration, while white ash produced a shallow root system with a great deal of lateral rooting. The other species showed great differences in the root systems they produced.

TABLE 64

Percent Tree Survival As Of 1972 For Various Species

	W. Ash	9-Bark	G Dog	Wayf Tree	S Dog	B Berry	R Olive	R Pine	J Pine	Crab
Milled	68	8	6	6	28	16	6	24	52	40
Unprocessed	74	42	39	45	39	57	19	30	39	74
Milled, Subsoil	66	4	4	0	28	0	0	20	30	20
Milled, Topsoil	70	14	8	14	30	30	10	28	74	60
Unprocessed, Subsoil	77	54	50	57	50	64	30	40	57	80
Unprocessed, Topsoil	70	30	37	37	27	50	7	20	20	67
Subsoil	72	28	27	27	39	32	15	30	44	50
Topsoil	70	22	17	25	28	40	9	24	47	63

The soil environment also greatly influenced the form and function of the roots. The root systems produced were all very shallow; the deepest rooting observed was 35 cm. The shallow rooting can be attributed to several soil properties. The soil had a very high soil strength which, in part at least, provided mechanical impedance to root extension. This is evident in that many of the roots were highly distorted and had flat tips. Other external, as well as internal, root characteristics can also be attributed to mechanical impedance as was discussed previously. High soil strength alone was not responsible for the reduced root systems, as seen by the extensive lateral rooting in many cases.

The water content of the soil also influenced the root systems produced. Low water content may prevent penetration, either directly or because of increased soil strength. Too much water may also limit root extension and efficiency due both to excess water and to deficient aeration in the root zone.

Soil aeration also limited root penetration and function in the study. This is evidenced by the shallow root systems produced and by the poor tree growth produced in spite of adequate fertility. Many dead roots occurred, as would be expected in a poorly aerated soil. Greater tap root and overall root penetration also occurred on the unprocessed as compared to the milled site, which was due to greater aeration on the unprocessed site assuming that there was, as earlier suggested, more gas production by milled refuse.

Several other rooting characteristics were noticed. Little increase in vertical root penetration occurred from 1971 to 1972; however, some increased in lateral rooting did occur over this period. It was also noticed that the amount of top growth produced by a given tree did not always correspond to the amount and vigor of its root system.

The grading necessary for preparation of the planting sites greatly compacted the soil. The amount of compaction occurring depended upon the soil texture. The topsoil which had only 12 percent sand was compacted to a bulk density of 1.72 g/cc., while the subsoil with 40 percent sand had a greater bulk density of 2.00 g/cc. Apparently, the finer separates filled in around the sand particles, and since the subsoil had a much higher proportion of sand, it was compacted to a greater degree. The grading operation also reduced the total porosity to 16 percent for the subsoil and 26 percent for the topsoil; it also caused the formation of a crust on the soil surface. The compaction caused by the grading operation greatly influenced the moisture, aeration, and strength characteristics of the soil. Compaction reduces pore sizes in soils so much that roots cannot make initial entry. This is especially true for coarse soils; but in finer soils the elongating roots may displace the soil particles enough so that the roots may push through. In this study, although the soil was of a fine texture, the moisture conditions interacted to prevent elongation. Under high moisture conditions inadequate aeration probably prevented root elongation, while under low moisture conditions a great increase in soil strength occurred to limit elongation.

Evaluation of Top Growth

Aside from growth measurements and tree survival, certain characteristics of the trees can be used to help evaluate their growth on the landfill environment. At the time of planting the unprocessed site, much of the planting stock had been badly degraded by a two-week cold storage period. The effect of this cold storage period is difficult to evaluate since the dry conditions existing on the unprocessed block (U) at the time of establishment also must be considered. The trees were greatly affected and many died, while others lost much of their terminal growth. In most instances, this appeared to be due to dehydration. Even after the initial establishment period, it was often noticed that many of the leaves suffered severe dehydration during dry periods.

Another instance of the effect of prevailing conditions on tree growth was seen in a depression in the planting site. Due to uneven settlement, a slight depression occurred on U which was filled with water during periods following rains. The trees planted there were very stunted and had very poor survival (16 percent remained alive in 1972). Apparently, the poor drainage greatly intensified the aeration problem.

Aside from these problems, other visible symptoms were noticed throughout the period of study. Several apparent nutrient deficiencies were encountered, particularly those indicating insufficient phosphorus and nitrogen. Insect damage was encountered to some extent each year. Also, several lesions were caused by various parasitic organisms. In similar studies, it might be quite advantageous to include treatments with various biocides to limit the effect of competing organisms.

Soil Physical Properties:

Soil Matrix

Bulk density values (P_b) determined on the two blocks (Table 65) were very high compared to values which would be expected on soils of similar textures, i.e., approximately 1.3 g/cc. Average values for the topsoil (1.72) and the subsoil (2.00) on the two blocks differ greatly. Such a difference is due to differences in the soil particles of the two types.

The particle density values (P_s) determined with pycnometers were nearly the same for both the subsoil and topsoil (average 2.38). Porosities were found to be 28 and 16 percent for the topsoil and subsoil, respectively. These values are far below the ideal porosity, which is about 50 percent.

High bulk density and low porosity have a great influence on soil strength and therefore on the mechanical impedance to root elongation. As discussed earlier, excavated roots were found to be restricted to the immediate area in which they were planted in most cases. High bulk

TABLE 65

Bulk Density, Percent of Separates, Soil Texture, and Porosity

	Bulk Density (g/cm^3)	Percent of Separates			Texture	Porosity (%)
		% Clay	% Silt	% Sand		
Milled Cell A	1.91	30	30	40	clay loam	19.7
Milled Cell B	1.92	33	35	32	clay loam	19.3
Milled Cell C	1.98	30	32	38	clay loam	16.8
Milled Cell D	1.65	35	57	8	silty clay loam	30.6
Milled Cell E	1.85	34	54	12	silty clay loam	22.2
Milled Cell F	1.57	32	56	12	silty clay loam	34.0
Unprocessed Cell A	2.09	28	20	52	sandy clay loam	12.1
Unprocessed Cell B	2.00	30	28	42	clay loam	15.9
Unprocessed Cell C	2.06	33	35	32	clay loam	13.4
Unprocessed Cell D	1.72	33	55	12	silty clay loam	27.7
Unprocessed Cell E	1.78	31	55	14	silty clay loam	25.2
Unprocessed Cell F	1.77	38	57	12	silty clay loam	25.6
Milled, Subsoil	1.94	31	32	37	clay loam	18.6
Milled, Topsoil	1.69	34	56	10	silty clay loam	28.9
Unprocessed, Subsoil	2.05	30	28	42	clay loam	13.8
Unprocessed, Topsoil	1.76	34	55	11	silty clay loam	26.2

densities often limit root growth and elongation. No roots are found at soil densities of 1.9 or above, while some clay soils stop penetration by roots at just 1.6 to 1.7 g/cc. The values found in the landfill are definitely high enough to cause root restriction. Although no absolute limiting bulk density can be given, it is very likely that the restricted root systems found on the landfill are due, at least in part, to the high bulk densities.

Results of penetrometer measurements show that the soil strength at the one cm depth is generally low, probably due to the effects of vegetation or because the dry crust cracked under the applied force rather than flowing as it did in the underlying soil. Lower depths in both landfill profiles were so impenetrable that readings were usually off scale. Very little difference was found in the soil strengths between the two landfill profiles despite their differences in bulk density and texture. The comparative data for the Arboretum soils show values quite uniform throughout the profile, rather than low values at the surface as in the landfill. In both Arboretum profiles, values are very much lower than those for deeper depths in the landfill. Since vegetation in the Arboretum is not restricted in penetration, as evidenced by extensive root systems, it follows that values obtained there (less than 3.7 kg/cm.^{2}) are below the force most roots can exert to achieve penetration. As indicated by the poor root expansion in the landfill, the high penetrometer values denote strengths which are limiting to root elongation.

Soil Water

The compaction of the soil also had a great effect on soil moisture. The soils were either too wet or too dry much of the second growing season. Soil compaction caused both a decrease in total porosity and a decrease in the proportion of small pores. The low total porosity provided very little pore space for water, and the space which did exist consisted largely of small pores. Thus, the soil had both low total water capacity and low available water capacity. The compaction also caused the formation of a crust which intensified the dry soil conditions by causing much of the rainfall received to run off. Low rainfall normally was encountered when the plants required the most; this, along with the low infiltration rate and the small amount of available soil water, often caused the soil to be too dry for optimum plant growth.

Aside from these dry conditions, the tensiometer data also show that the soil was saturated at many times during the growing season. These periods normally occurred following heavy rainfall and at the end of the growing season when evapotranspiration rates were low. Large amounts of rainfall were able to completely saturate the soil pores. The low hydraulic conductivity and high moisture retention then caused the pores to drain very slowly, greatly intensifying soil aeration problems.

Aeration

Compaction, then, controlled aeration by affecting total pore space, pore-size distribution, and water retention. Since there was little pore space, little space existed for air. Because most of this pore space was made up of small pores, the pores were quite often occupied by water. Besides displacing soil air, soil water also reduced the gas diffusion rate of the soil. The diffusion rate is proportional to the fraction of total soil volume consisting of gas-filled pores. The amount of gas-filled pore space was found to be only 12 percent at a tension of 15 bars, while at 0.3 bars (field moisture capacity) only 7.6 and 9.1 percent of the total pore space was occupied by air for subsoil and topsoil, respectively. Critical levels for gas-filled pore space are 10 to 15 percent at field moisture capacity. Thus, it is seen that the trees are growing at near critical levels of aeration.

This poor aeration situation is greatly worsened by the landfill environment; the underlying refuse produces large quantities of carbon dioxide and methane which diffuse upward and displace much of the oxygen in the soil. Thus, the quality of the soil air is quite unlike that existing in "normal" field soils. Gas samples showed that little or no oxygen existed in the root zone on several occasions. Methane and carbon dioxide have not been proven to be toxic, but their presence is very harmful because they displace oxygen which normally occupies the soil pores (Table 66). Thus, the gases produced by the refuse along with the low amount of gas-filled pore space provide a great obstacle for developing trees. There may also be some problem with accumulation of toxic substances due to the anaerobic conditions; however, this was not investigated.

In summary, it is quite obvious that soil aeration on the site is very poor. The production of carbon dioxide and methane by the refuse, in conjunction with the low amounts of gas-filled pore space, provides a great obstacle for growing trees. Thus, it can be hypothesized that the high mortality in the fall and winter of 1971-72 was in part due to insufficient oxygen present in the rooting zone.

Temperature

On several refuse cells without soil caps, it had been noticed that snow would not accumulate due to heat production from the decomposing refuse. Soil temperatures were monitored on the milled refuse block to determine if growth might continue throughout part or all of the winter months because of heat production by the underlying refuse.

The temperature measurements, however, indicate that the refuse had no detectable effect on the soil temperature. The soil temperatures reached - 16°C at one of the diodes, and the soil remained frozen for several months of the year. The data show that the shallower depths were more responsive to the external environment than the greater depths, as would be expected. The refuse apparently had little effect on soil temperature as witnessed by the later thawing of the deeper soil in the spring.

TABLE 66

Composition of Soil Atmosphere at Various Depths

Plot*	Distance to Surface (Cm)	Distance to Refuse (Cm)	% CO_2				% O_2				% N_2				% CH_4			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
A	50	2		41	37	42		TR	TR	--		15	35	2		44	28	56
A	30	22		35	28	39		TR	TR	TR		28	57	12		--	--	--
A	15	37		--	--	--		4	8	22		96	92	78		--	--	--
B	56	2	--	--	--	--	13	19	17	21	87	81	83	79	--	--	--	--
B	30	28	--	10	23	34	7	5	4	2	93	59	32	14	--	26	41	50
B	15	43	31	25	23	39	--	TR	3	TR	53	45	65	4	16	30	10	57
C	30	20		43	43	7		TR	TR	17		5	3	68		52	54	7
E	55	2	--	--	12	22	20	4	4	3	80	85	50	28	--	11	34	47
E	30	27	21	15	7	30	4	6	13	4	42	79	80	39	33	TR	TR	28
E	15	42	--	--	TR	10	17	17	18	11	83	93	82	75	--	--	--	4

1 = May 22
2 = June 13
3 = June 27
4 = August 1

*From November 1970 to September 1971.

Another observation is that some of the trees may have been injured or killed due to heaving in the winter months. This is a distinct possibility in that moist, dense soils such as these are quite subject to heaving. Although no trees were lifted completely out of the ground, it is quite likely that some roots were injured due to frost heaving.

Soil Chemical Properties:

The fertility status of most soils can be determined quite well by the combined use of soil and foliar analyses. Although neither is completely reliable, together they usually point out any major fertility problems.

The values obtained in the soil analyses were compared to minimum critical levels of soil fertility for three groups of trees based on their nutrient requirements: microtrophs (least demanding), mesotrophs (medium demanding), and megatrophs (highly demanding) (Wilde, 1958).

Tissue analyses were made of foliar samples of white ash, jack pine, and red pine taken from portions of the milled and unmilled plots, from three different fertilizer treatments, and from reference plots which were used to compare values obtained for the three species. The foliar values were then compared to values given by Gerloff, Moore, and Curtis (1964) for each of the above species. Jack pine and red pine samples were analyzed for N,P,Ca, and Mg, while white ash samples were also analyzed for K, Fe, Sr, B, Cu, Zn, and Mn.

Several trends in the availability of the nutrients can be seen. First of all, the results of the analysis for N, P, K, Ca, Mg, organic matter, and pH will be discussed.

Using a combination of soil and foliar analyses, it was possible to locate possible nutrient deficiencies existing in the landfill. From the slow rate of growth and the high mortality of many of the species, nutrient deficiencies might be expected. The chlorosis of many of the trees and abnormal coloration of others also leads one to believe that some nutrients are deficient. From the soil and foliar analyses, however, it seems that it is probably physical limitations, rather than chemical ones, which are causing the poor tree growth and symptoms found. Based on reference values used to compare the results of the analyses, only a general index of possible deficiencies may be given. The levels for soils established by Wilde, for example, may be sufficient under normal field conditions, but the primitive soil conditions existing in the landfill might require completely different recommendations. This is because of greatly different root zone conditions and the highly anaerobic conditions existing much of the time in the landfill.

In spite of these problems, certain conclusions may be drawn from the analysis. Nitrogen levels in the subsoil were near microtroph levels while the topsoil was above the level established for megatrophs. The chlorotic symptoms were seen in plants on both the topsoil and subsoil, so they were likely caused by something other than soil nitrogen deficiencies. This is supported by the high foliar levels found in white ash, a species demanding relatively high levels of nitrogen. Phosphorus was found to be in the mesotroph range for both topsoil and subsoil in most cases, and foliar levels were near the prescribed levels. Thus, phosphorus is probably not limiting tree growth in the landfill. Potassium levels in the subsoil were in the mesotroph range while the topsoil was above megatroph levels. The foliar analysis for potassium must be discounted because of leaching due to rinsing. However, from the soil analysis, it seems that potassium is not a limiting nutrient either. Calcium and magnesium levels are very high in the soil, so it seems unlikely that they might be limiting. There may be some problem, though, with ion interaction between calcium, magnesium, and potassium. There may also be some additional problems because of the somewhat high pH. Although the pH is not high enough to cause any problems directly, it may cause some changes in the availability of some of the nutrients. The low organic matter content of the US and fertilizer plots may also have caused some problems. These plots are even below the levels recommended for jack pine, which grows well on soils very low in organic matter. Even the topsoil and No. MS plots are well below levels suggested for hardwoods. Trace element levels are poorly understood, But there may be some deficiencies or toxicities occurring because of the anaerobic conditions and high pH present in the landfill. The fertility status of the landfill soils is generally adequate for tree growth. It appears that the factors limiting tree growth are more likely physical than chemical.

Fertilization Experiment:

The fertilizer experiment consisted of applying fertilizer packets to the root zones of white ash, jack pine, and red pine to determine their response to fertilization. Some of the treatments included loose fertilizer as well as packeted fertilizer. The results of the experiment show no height or diameter response to any of the applied fertilizer treatments. Although there was no growth response, neither was there any increase in tree mortality due to fertilizer treatments. Perhaps the one-year period was to short to get much response, but it seems quite unlikely that a response would occur at a later date. Limitations due to deficient moisture, deficient oxygen, or high soil strength quite likely were responsible for the lack of response. Because root systems were limited in extent by these properties or because deficient oxygen limited nutrient uptake by existing root systems, fertilizers were not utilized by the trees in sufficient quantities to cause measurable growth changes.

RECOMMENDATIONS

In order to make recommendations concerning site preparation, tree planting, and cultural practices to maintain trees on landfill sites, it is necessary to make certain initial qualifications. The recommendations will depend upon the proposed use of the landfill, the composition and preparation of the refuse, the kinds of soil materials available, and the characteristics of the site.

Most landfills are normally in an urban environment, and therefore will probably be used for recreational purposes. Thus, aesthetic rather than economic considerations are normally most important. However, under different conditions, trees might also be planted for more economic reasons. Choice of a species, then, depends upon use since trees grown for aesthetic reasons should be chosen primarily on the basis of survival and appearance while overall growth is more important for economic purposes.

The refuse composition and preparation will also influence these choices since the type and amount of gas production is determined by the refuse. This study showed significantly better survival on unprocessed than on milled refuse; this was attributed to less early gas production by unprocessed refuse. Refuse composition might also cause some differences in the type of gases produced and the rates of decomposition. There may also be large differences in gas production over time; allowing refuse to decompose for several years before covering and planting may give the trees a much better chance for survival.

The type of fill material available for use and the preparation of the site for planting will influence the soil and tree species recommended. Economic considerations must enter in to determine how much time and expense should be expended to achieve the desired results.

Fine-textured soils normally have the best aeration under low moisture, but under high moisture conditions coarse-textured soils normally have better aeration. Fine-textured soils also have better moisture retention, so if drainage is not normally a serious problem, a better supply of moisture is provided during dry periods. Coarse-textured soils provide better drainage but are often too dry during periods of drought. Fine-textured soils normally also have the greatest soil strength except under very high moisture conditions. A well-structured medium texture soil such as a silt loam, either topsoil or subsoil, will have adequate aeration but will still have enough moisture retention to provide adequate moisture.

The fertility of the soil cover will depend on its origin; soil analyses will give approximate nutrient levels and indicate whether fertilizer may be helpful. In later years, nutrient deficiency symptoms and foliar analyses can be used to determine fertilizer requirements. The use of topsoil rather than subsoil also calls for increased weed control measures since a greater carryover of weed seeds normally accompanies topsoil.

Once the type of soil is decided upon, the depth and method of application must then be determined. The results of this study showed that the additional layer of topsoil increased both survival and growth of the trees. This increase was attributed to the extra 15 cm. of topsoil providing greater aeration in the root zone. The added layer acted as a buffer between the tree roots and the refuse. The somewhat greater porosity of the topsoil also may have contributed to better aeration in the root zone. Soil depth may not be as important when the soil is less compacted, but providing a thick soil layer seems to be very good insurance against deficient aeration in the root zone. Another reason for providing a thick layer of soil cover is that wind throw may be prevented by giving the root systems adequate soil volume in which to anchor themselves. A method of application of the soil cover should be used which will limit the amount of compaction as much as possible.

The determination of tree species to be planted will depend greatly upon the proposed use of the landfill. For recreation purposes, however, species should be used which have relatively fast establishment and low mortality; growth is normally not a major consideration. Tree mortality is normally greatest during this establishment period. Of the species used in this study, white ash, wayfaring tree, buffaloberry, and crab suffered the least mortality during the first year; therefore, these species may be the best suited for establishment. White ash and buffaloberry also achieved greater growth the first year compared with red and jack pine. White ash is known to be rapidly established and also grows well in dense soils.

White ash and crab suffered the least mortality of any of the species for the entire study period. Past research has shown that white and green ash, along with cottonwood, normally do very well under poorly aerated soil conditions. The rooting habit of white ash may be responsible for its success; it produced primarily lateral roots and thus concentrated its root system in the better-aerated upper soil layer. Research on spoil banks has shown red and jack pine to be very reliable evergreens normally, but the results of this study disagree. This perhaps is because of the dense soil and poor aeration; these pines quite likely will grow much better under less compacted conditions.

An additional factor of concern is that the tree roots will quite likely enter the underlying refuse if the compacted soil conditions are alleviated and better root growth occurs. What will happen upon their penetration is not known; however, it seems quite likely that they will not penetrate the refuse to any extent because of probably poor aeration, low moisture, and concentrations of toxic substances in the refuse. The trees will quite likely remain rooted in the soil for the most part if the soil layer is of sufficient thickness.

A final consideration is that if a tree will be growing under less than ideal conditions, it is usually best to plant relatively small seedlings which can adapt their root systems to the rooting environment that they are planted in. However, there are certainly some situations in which larger trees would be more desirable for planting. Planting larger trees would greatly speed their growth to a size at which they would be more useful from an aesthetic and functional viewpoint. Larger trees should be planted in large planting holes and the holes should be backfilled with a rich soil having good structure. Planting of small seedlings may be done directly into the soil cover as done in this study, but the addition of a mulch material along with sufficient fertilizer will undoubtedly increase growth and survival. The mulch will substantially increase the water-and nutrient-holding capacity of the soil. Fertilization should be done on the basis of a soil test since no benefit will be derived if the soil levels are already adequate. Irrigation may also be necessary to obtain adequate survival, especially the first year.

In summary, a medium texture, well-structured soil material should be applied to the refuse using a method which limits compaction as much as possible. The depth of soil material should be as great as is economically feasible, providing adequate soil volume for root expansion and a buffer between the root system and gases produced by the refuse. Species to be planted should have the ability to develop a lateral root system with diffuse branching; white ash and crab developed such a root system in this study. Relatively small seedlings should be planted in planting holes which have mulch material and fertilizer packets added. In cases where the planting of larger trees is more desirable, planting holes should be backfilled with topsoil and a mulch material to provide a good initial root environment.

OTHER VEGETATION

Unless an uncovered cell of milled refuse is continually worked, volunteer vegetation will develop in one or two years after placement. During the summer of 1968, a diverse plant community, ranging from weeds to garden vegetables (Figure 107) to trees, became established spontaneously on all the milled uncovered cells at the Olin Avenue site. This growth may have been due in part to seeds in the refuse itself. Heavy plant growth has continued on the milled cells in subsequent years. In fact, the vegetation on the milled refuse cell is so dense that it is difficult for an observer standing on an old milled refuse cell to see that he is indeed on refuse and not on soil (Figure 108).

Also in 1968, a slimy growth was noted on many of the milled uncovered cells. It persisted throughout the summer and reappeared the next year. It was identified as a slime mold, Fuligo septica, which is commonly found in heavily wooded areas. It grows on material of high cellulose content. This slime mold is not a threat to public health.

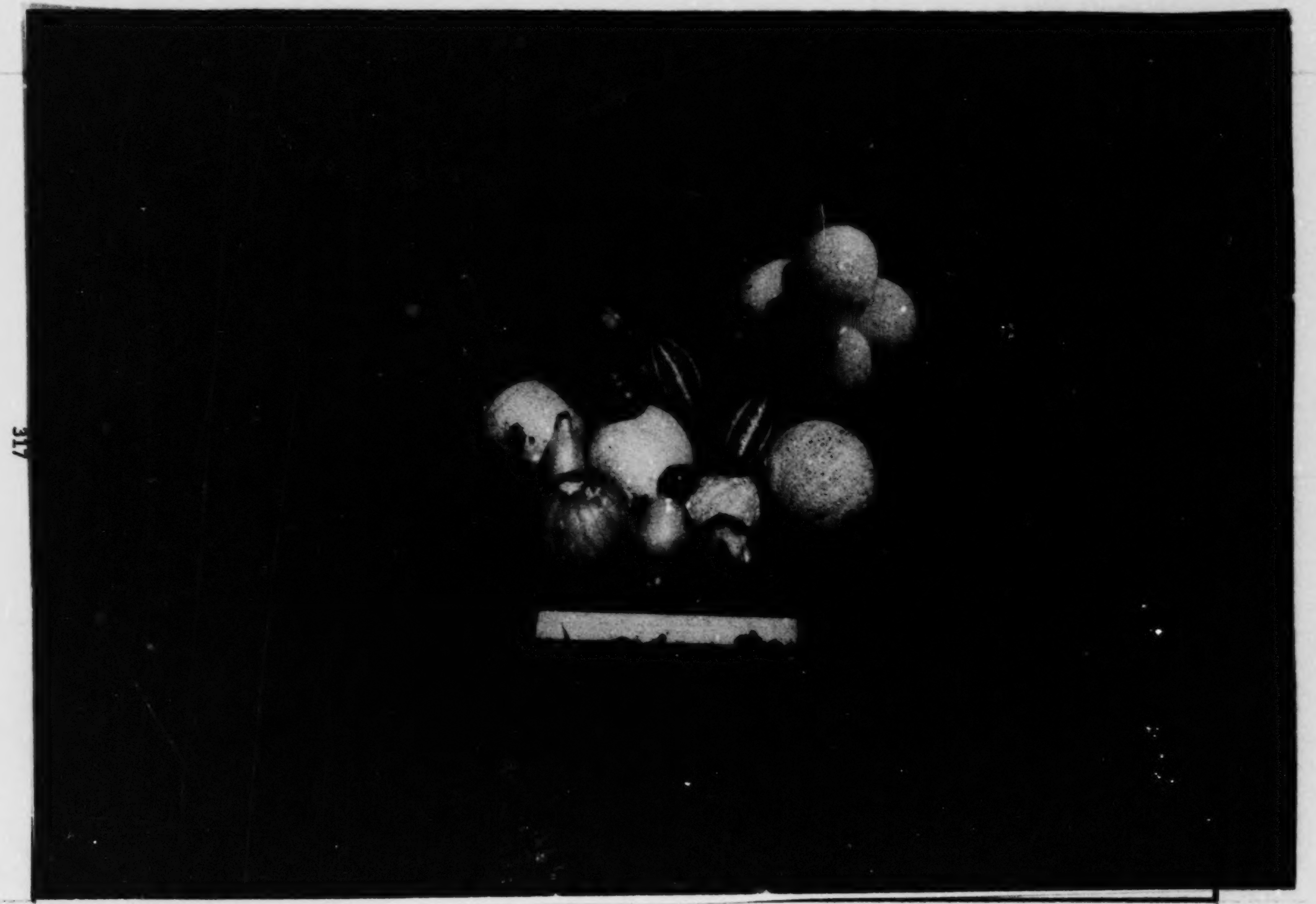

Figure 108. Some Products of Volunteer Vegetation on Olin Avenue Milled Refuse Landfill, Madison, Wisconsin

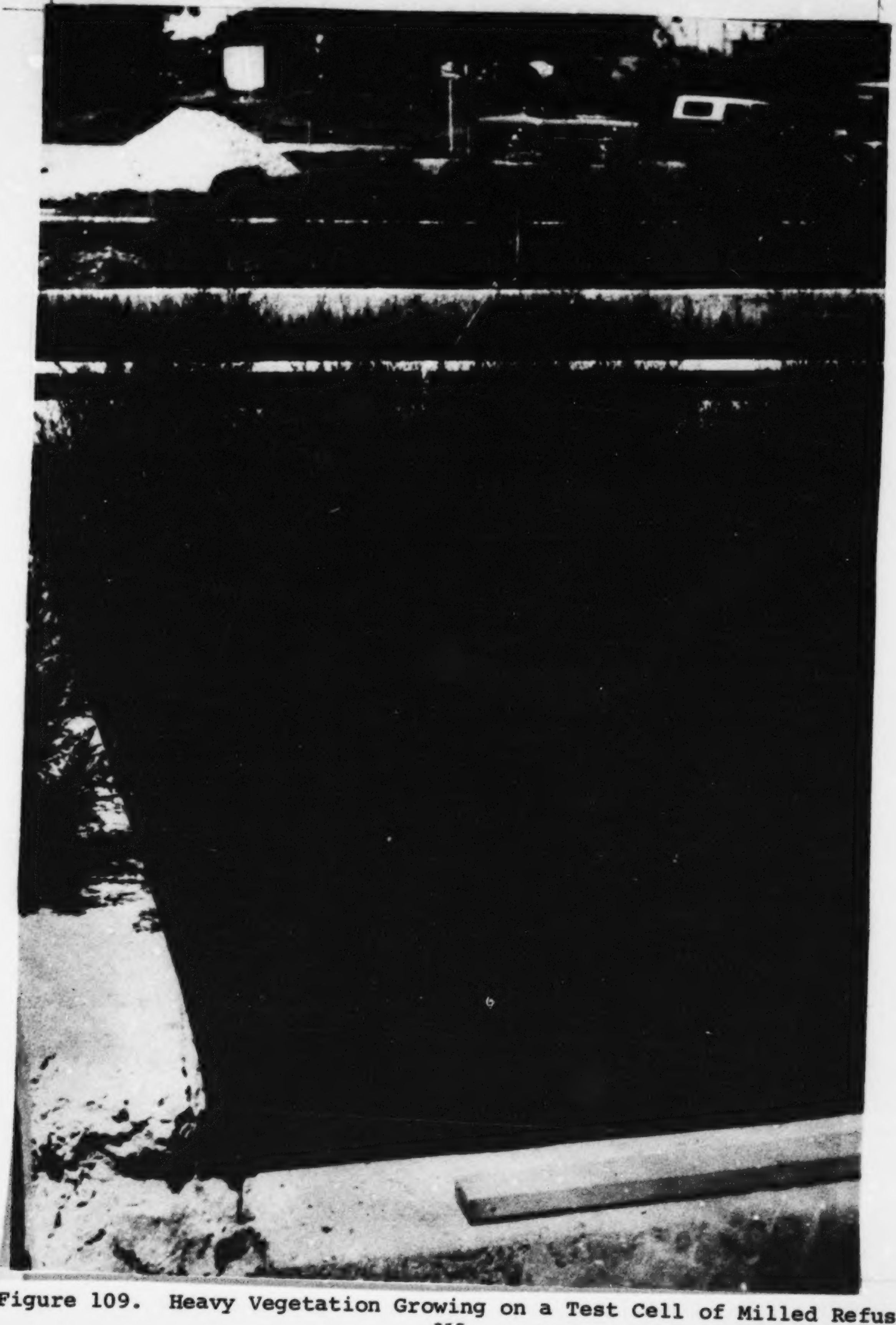

Figure 109. Heavy Vegetation Growing on a Test Cell of Milled Refuse

VIII OTHER OBSERVATIONS

VIII-A - Fire

INTRODUCTION

A series of tests on the fire hazards from milled refuse in a landfill was conducted in August 1969. These tests were performed by the Madison Fire Department at the Olin Avenue Landfill.

Ignition of the milled material in all tests was from heat sources likely to be encountered under normal landfill conditions. Test situations simulating grass fires, airborne flying embers, and accidental ignition of spilled fuel oil were carried out on milled refuse cells of various ages. The fires that occurred as a result of these ignition sources were mainly superficial and allowed for close approach (Figure 110) to observe both the rapidity of spread and the intensity of heat generated. One special test was conducted to obtain some data relative to burning conditions in the interior of a storage cell. This test was not intended to simulate a realistic condition.

Three experimental milled refuse cells were used for the test fires. Two of the cells were over one year old and the third was a special cell constructed within a month of the time the fire tests were conducted.

The development of a suitable means of fire control and extinction was also to be determined from these tests.

Following are the reports and analyses of the various fire tests on milled refuse cells.

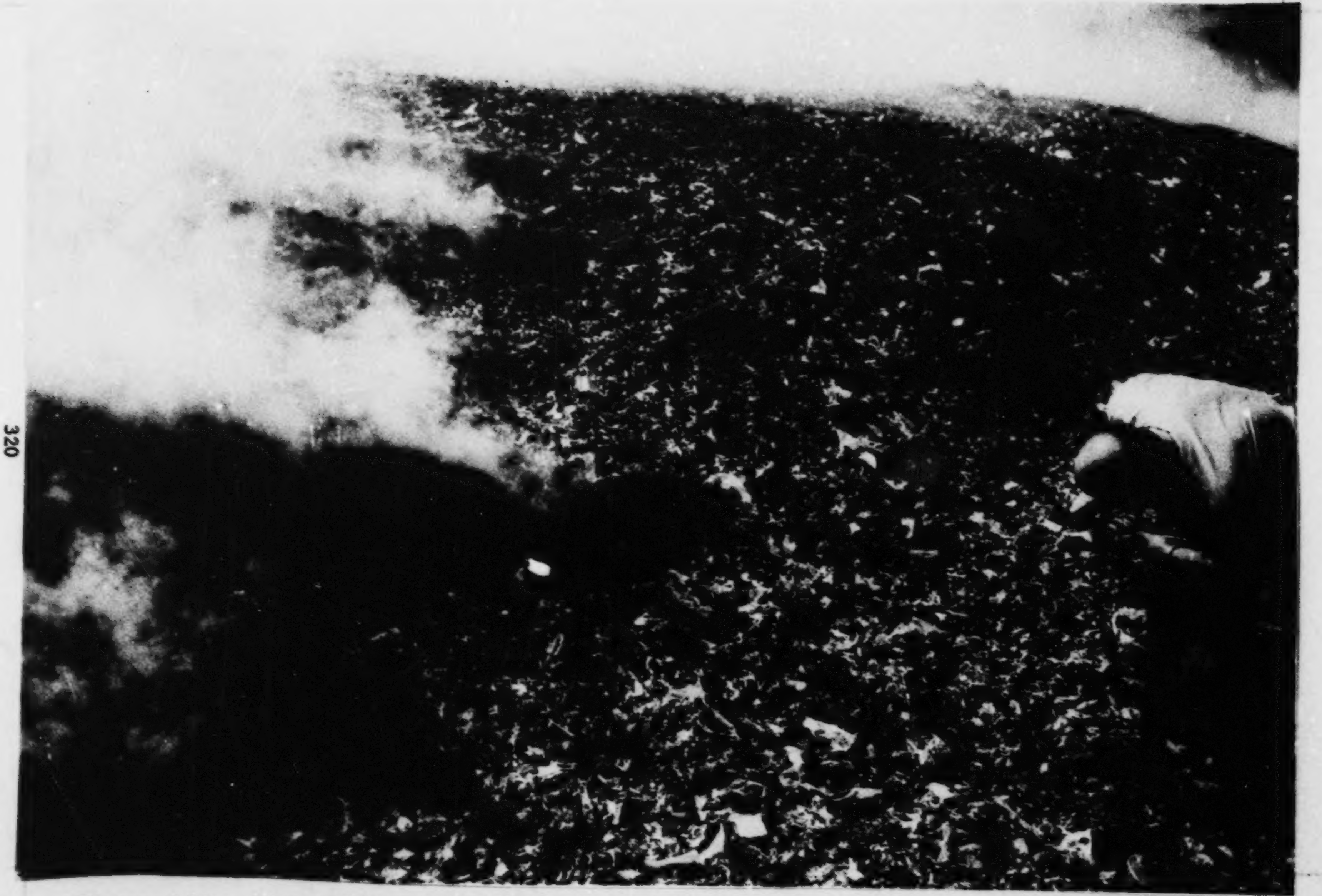

Figure 110. Fire Deliberately Started on Fresh Milled Refuse Caused Smoldering, but Remained on the Surface and was Easily Extinguished

Figure 111. Wind-Blown Film Plastic From Milled Refuse Landfill

VII. MADISON FIRE DEPARTMENT
FIRE TEST

Location Refuse Reduction Plant-Olin Avenue Date August 18, 1969

Fire Type Fuel Spill Simulation Cell Number 35 Cell Depth 5½ Ft.

Cell Size 88' x 98' Cell Formation Date April 1, 1968 Temperature 74 F.

Location of Fire on Cell E. end-midpoint top Relative Humidity 66%

Ignition Start Time 9:08 A.M. Burning Time 45 Min.

Extinguishing Method Burned Out Wind Velocity-Natural 6 M.P.H.

FIRE TEST NUMBER ONE Artificial None M.P.H.

COMMENTS:

The first test fire was one intended to simulate a fuel spill as a result of automotive equipment working on top of the cells. Fuel containing a ratio of 4 gallons of diesel fuel to 1 gallon of drained crankcase oil was used. An area of approximately 5' x 5' was covered with the fuel. A small amount of gasoline was poured at one corner of the spill and ignited. The fire burned rapidly at first, generating considerable amounts of heat. When the larger flames died down the remaining fire consisted of flames about 6 inches in height being fed by the vapors as a result of the fuel spill. When the milled material was agitated, larger flames again appeared. This action seemed to indicate the milled material had the ability to trap the fuel vapors at levels below the surface fire limiting the volumes dissipated. The agitation of the material was continued until no fire could be sustained by this method. The fire burned out completely in 45 minutes. Examination of the burned area after the fire was out indicated negligible penetration of the fire. Perimeter extension of the fire was about 6 to 12 inches. The fire remained entirely on the surface and appeared to burn only the very small particles of combustible material lying on the surface. Very little ash was present and the burned area had a charred appearance. During the fire the wind had little or no effect on the spread of the fire.

CONCLUSIONS:

Because of the length of storage time, compactness of the milled material, and the moisture content within the cell it appeared unlikely that a fire started by an incident of this type would be capable of involving the stored milled refuse to any degree.

OBSERVERS: Warren Porter, John Tappen, Douglas Bailey, Donald Huggins, Vincent Geier

MADISON FIRE DEPARTMENT
FIRE TEST

Location Refuse Reduction Plant-Olin Avenue Date August 18, 1969

Fire Type Simulated Flying Embers Cell Number 16 Cell Depth 5½ Ft.

Cell Size 88' x 98' Cell Formation Date April 1, 1968 Temperature 74 F.

Location of Fire on Cell Midpoint-top Relative Humidity 66%

Ignition Start Time 9:52 A.M. Burning Time 5½ Hrs.

Extinguishing Method Burned Out Wind Velocity-Natural 5 M.P.H.

FIRE TEST NUMBER TWO Artificial None M.P.H.

COMMENTS:

The second test fire was a simulated flying embers exposure type incident. Approximately 5 pounds of charcoal was ignited in a separate container and when all the coals were glowing they were placed on the milled material. These coals burned for a period of 5½ hours. Examination of the burned area at this time showed no indication of any penetration vertically in the milled refuse. Horizontal spread was limited to several inches directly adjacent to the coals. The coals did not have the ability to ignite the very small pieces of combustible material on the surface. This produced sporadic flames several inches in height but of very short duration. The wind had no effect on this fire.

CONCLUSIONS:

Because of the length of storage time, compactness of the milled material, and the moisture content within the cell, it appeared unlikely that a fire could be started by an incident of this type.

OBSERVERS: Warren Porter, John Tappen, Douglas Bailey, Donald Huggins, Vincent Geier

MADISON FIRE DEPARTMENT
FIRE TEST

Location Refuse Reduction Plant-Olin Avenue Date August 18, 1969

Fire Type Simulated Grass Fire Cell Number Mill Spoil Cell Depth 5½ Ft.

Cell Size 50' x 98' Cell Formation Date June 1, 1968 Temperature 74 F.

Location of Fire on Cell S. E. Corner-Base Relative Humidity 66%

Ignition Start Time 10:21 A.M. Burning Time Approximately 4 hours

Extinguishing Method Water (100 gallons) Wind Velocity-Natural 4 M.P.H.

FIRE TEST NUMBER THREE Artificial 8 M.P.H.

COMMENTS:

The third test fire performed was a simulated grass fire. During the time of structure of the cells, the sides are naturally formed at approximately a degree angle of 60. It appeared at the time of burning a certain erosion process had taken place during the storage period and the finer materials had washed away and only the more coarse materials remained. This action formed horizontal ridges or protrusions of materials on all sloped sides. The top surface of the cell was very compact in relation to the material forming the sides of the cell. Two bales of hay were spread at the base of the milled material cell. Fans were set up to increase the wind velocity. This was done because the fire was to be ignited in what was a gully formed by the adjoining cell and natural wind velocity at this location was negligible. This procedure was continued for 30 minutes. The hay in the center of the bale was damp and approximately one quart of gasoline was used along the farthest outside edge of the hay for rapid ignition of the total edge. Upon ignition the fire spread through the hay and up the slope of the cell and traveled across the horizontal surface at the top of the cell, burning off grass that was naturally present at this time of year. This natural grass failed to ignite the milled material. The fire traveling up the vertical slope ignited the ridges of the milled material and did sustain combustion. Flame propagation was not of great dimensions but did continue visibly for a period of one hour. At this stage the fire was definitely a smouldering type, giving off considerable quantities of heat. The fire continued to burn for a period of 4 hours before extinguishment took place. Examination of the burned area revealed a spread of fire beyond the hay placement of about 6 feet in length and maintained the approximate width of the hay placement. Depth of fire penetration in isolated spots reached a maximum depth of about 9 inches. Generally the burn penetration was negligible and consisted, to a large degree, of surface material charring. Extinguishment was a relatively simple matter using a quarter inch nozzle and approximately 100 gallons of water after 4 hours of burning time.

CONCLUSIONS:

It would appear that a fire starting at the base of this cell would have the ability to burn in a vertical direction toward the top of the cell. Moisture content would restrict deep penetration by fire of the stored material. Green natural cover such as grass or weeds would practically eliminate any possible spread of fire at the top horizontal surface of the material cell. From a fuel source hazard standpoint, the stored milled material of this age would have to be considered as slight.

OBSERVERS: Warren Porter, John Tappen, Douglas Bailey, Donald Huggins, Vincent Geier.

MADISON FIRE DEPARTMENT
FIRE TEST

Location Refuse Reduction Plant-Olin Avenue Date August 18, 1969

Fire Type Buried Heat Element Cell Number 15 Cell Depth 5½ Ft.

Cell Size 88' x 98' Cell Formation Date April 1, 1968 Temperature 74 F.

Location of Fire on Cell Center (3' Depth) Relative Humidity 66%

Ignition Start Time 11:10 A.M. Burning Time Undetermined

Extinguishing Method None Wind Velocity-Natural M.P.H.

FIRE TEST NUMBER FOUR Artificial M.P.H.

COMMENTS:

A final test was performed in an effort to gain some data on burning situations within the milled refuse. Previous gas analysis made on the various cells at various levels indicated that at times sufficient oxygen was present to sustain combustion. Temperatures thus far recorded have reached a high of 140 degrees F. at certain levels. In order to generate the necessary ignition temperature within the milled refuse, an electric heating element was placed at a depth of three feet. The element used was an 1175 watt resistance type element, and was placed directly on the milled material. Approximately eight inches of milled material was spread over the top of the element and compacted. At this point a thermocouple was placed to record temperatures within the milled material that would be produced by the heating element. More milled material was applied and compacted at regular intervals until the top elevation of the cell was reached. A portable generator was used to supply the energy necessary for the heating element. The generator was run for a period of four hours. All during the time the heating element was energized, attempts were made to record the temperature of the milled material at the thermocouple without success. This later appeared to be a result of too great a distance between the heat element and the thermocouple. The buried element was left untouched for a period of twenty hours at which time exhuming took place. Removal of the material from above the element was carefully checked at all levels for heat and smoke indications. At approximately two inches above the element, charring was noticeable. A certain amount of heat was present but was not of the degree to be uncomfortable to the touch. No smoking of the material was in evidence. Complete uncovering and removal of the element showed a charring of approximately two inches in all directions from the element outline. Examination of the charred material revealed it to be of a brittle nature.

CONCLUSIONS:

Evidence gained with this test indicates a deficiency of oxygen at levels within the refuse necessary to support combustion. This test was not intended to simulate a realistic condition, but rather to determine if burning could be accomplished and sustained within a cell.

OBSERVERS: Warren Porter, John Tappen, Douglas Bailey, Donald Huggins, Vincent Geier

MADISON FIRE DEPARTMENT
FIRE TEST

Location Refuse Reduction Plant-Olin Avenue Date August 26, 1969

Fire Type Fuel Spill Simulation Cell Number Special Cell Depth 5 Ft.

Cell Size 64' x 91' Cell Formation Date Aug. 8, 1969 Temperature 61 F.

Location of Fire on Cell S. W. end - Top Relative Humidity 84%

Ignition Start Time 8:55 A.M. Burning Time 11 days

Extinguishing Method Water Wind Velocity-Natural 2.5 M.P.H.

FIRE TEST NUMBER FIVE Artificial 13 M.P.H.

COMMENTS:

Where as the previous fire tests were accomplished on cells stored for over a period of one year, the following tests were made on a cell developed within the last two weeks. Again the ignition methods used were heat sources likely to be encountered under normal storage conditions. Burning characteristics of the material along with the development of fire control methods were also included as part of these final tests. Fuel used on this test was the same as that previously used. Area covered by the fuel was 40" x 66". Upon ignition the fire burned rapidly where the fuel had been spilled, and generated considerable amounts of heat. It became very apparent that because of the lack of moisture content of this newer cell and the small amount of settling and compacting, that this fire was capable of spreading readily. After approximately five minutes, the burning area had increased in size, and involved an area five times as great. During the course of the fire spread very little flame was visible, except in the initial spill area. Because of the lack of natural wind we again set up fans to create a wind situation. Twenty minutes after ignition the fans were started. Wind velocity was measured at 13 M.P.H. To some degree this did have the effect of spreading the fire faster. Because of the use of heavy tracked vehicles during the forming of the cells, ridges were created by the tracks and the fire did not spread readily across these indentations. Although this did appear to be an obstacle in the spreading of the fire, it eventually did burn across. The fire continued to spread laterally in all directions as well as burning downward. At this point it was very obvious the fire would not be restricted to a surface fire and burn itself out as had happened in the older cell. When it appeared that all flame action had ceased, flames could be made to appear by walking through the area of the original spill of the fuel. This apparently was caused by vapors trapped below the surface of the material. At this stage of the fire a limited amount of water was used on the fire in certain areas to determine how difficult it would be to extinguish. Eighty gallons of water through a quarter inch tip was used with good results. Although complete extinguishment was not accomplished because this was not desired, it was felt the fire could have been completely extinguished with a limited amount of water.

FIRE TEST NUMBER FIVE

CONCLUSIONS:

It is possible to ignite the surface of this milled refuse from an outside source such as a fuel spill fire. Once a surface fire has started the fire will spread throughout the entire cell. The two major factors which appear to effect a surface fire and the subsequent spread of the fire are the moisture content of the milled refuse and the compactness and settling of the cell. Wind did not appear to be a large factor because of the lack of flame. Smoke initially would be a nuisance factor but is drastically diminished as the combustible material on the surface is consumed by the fire.

OBSERVERS: Donald Huggins, Vincent Geier

MADISON FIRE DEPARTMENT
FIRE TEST

Location Refuse Reduction Plant-Olin Avenue Date August 26, 1969

Fire Type Simulated Ember Exposure Cell Number Special Cell Depth 5 Ft.

Cell Size 64' x 91' Cell Formation Date Aug. 8, 1969 Temperature 73 F.

Location of Fire on Cell S. Side Top Relative Humidity 76%

Ignition Start Time 9:55 A.M. Burning Time 11 days

Extinguishing Method Water Wind Velocity-Natural 2.5 M.P.H.

FIRE TEST NUMBER SIX Artificial None M.P.H.

COMMENTS:

Charcoal again was used to simulate a flying ember type of heat source for this test. The charcoal after being placed on the milled material was sufficient for ignition to take place. First indications were that the spread would be slow. After a five minute burn the fire was observed as to size and again at ten minutes. During this time the area of involvement was increased five fold. All during the burning, it was difficult to observe much flame propagation. As in other tests the flames were sporadic, several inches in height and of very short duration. Although the fire was spreading in all directions, no attempt to extinguish it was made at this time.

CONCLUSIONS:

Same as on test fire number five.

OBSERVERS: Donald Huggins, Vincent Geier

MADISON FIRE DEPARTMENT
FIRE TEST

Location Refuse Reduction Plant-Olin Avenue Date August 26, 1969

Fire Type Simulated Grass Fire Cell Number Special Cell Depth 5 Ft.

Cell Size 64' x 91' Cell Formation Date Aug. 8, 1969 Temperature 73 F.

Location of Fire on Cell W end Base Relative Humidity 76%

Ignition Start Time 10:20 A.M. Burning Time 11 Days

Extinguishing Method Water Wind Velocity-Natural 2.5 M.P.H.

FIRE TEST NUMBER SEVEN Artificial 6 M.P.H.

COMMENTS:

Because of the difficulty experienced when executing Fire Test Number Three, relative to the hay being damp, we immediately on arriving at the site spread the hay on the ground to allow it a period of two hours to dry. The quantity again was two bales, spread loosely at the base of the cell. Lack of appreciable wind velocity made the setting of fans a necessity if any determination of wind being a factor in the spread of fire in this material was to be evaluated. Ignition of the hay was made in the center of the spread material. The fire spread through all of the hay rapidly, producing flames of from four to five feet in height. Large quantities of white smoke soon appeared and indicated that the hay was not completely dry. Within a period of ten minutes all flaming action in the hay had disappeared and only a smoldering action remained. The hay fire was sufficient to be an ignition source for the stored milled material. Because of the wind involved, the fire spread relatively fast across and up the entire end slope of the cell. When the fire reached the top of the cell, its progress was approximately the same as that involving the other two test fires on this cell.

All three test fires conducted on this cell were allowed to burn and within a period of five hours the entire top surface of the cell was involved.

CONCLUSIONS:

Same as on Fire Text Number Five.

OBSERVERS: Donald Huggins, Vincent Geier

SPECIAL CELL FIRE ANALYSIS

Test fires numbered five, six, and seven, which were conducted on August 26, 1969 involving the special cell were allowed to burn in an effort to gain data relative to rate of spread, heat generated, smoke and flame conditions, and fire control and extinguishment methods. Burning was allowed to continue for a period of eleven days.

On the day the fire was extinguished, September 5, 1969, the physical makeup of the cell consisted of a top layer of light ash six to eight inches in depth, followed by a three to four inch layer of charred material, with a total burned depth of from nine to twelve inches. Observations made prior to the time of extinguishment indicated that the combustion process was retarded as time progressed and the fire became deep seated. The spread was in a very uniform manner and formed no pockets within the cell.

On August 27, 1969 temperature readings were taken at various locations and depths on the cell. Surface temperatures on the top of the cell were 405 degrees Fahrenheit. At a depth of three inches a temperature of 505 degrees Fahrenheit was recorded and at six inches a temperature of 200 degrees Fahrenheit was present. Surface temperatures on the windward side on the sloped bank were recorded at 604 degrees Fahrenheit, and in the same location on the leeward side at 315 degrees Fahrenheit. Temperature readings were again taken on September 4, 1969 on the top surface of the cell in approximately the same location that the first reading was taken. The surface temperature was recorded at 180 degrees Fahrenheit and at a depth of eight inches a temperature of 580 degrees Fahrenheit was recorded. At this point it became evident that the temperatures recorded were well within the ignition temperatures of the greatest percentage of the components making up the milled refuse, and that combustion would continue.

Smoke and flame conditions were observed on all days while burning took place. No flame was visible at the end of the first day that ignition was started. While digging in the pile to determine burn depth, the instant the ash cover was removed and the material turned over, it burst into flame. This was an indication that the rate of combustion was slow and that the absence of sufficient oxygen was the prime factor in restricting the fire to a smoldering type. Flame flare up was visible in isolated instances when a material with a rapid burning rate, such as some forms of plastic reached its ignition temperature. All during the burning period, only moderate wind velocities were recorded. It was felt that if severe winds had been prevalent, that the loose fly ash covering the cell could have been dissipated and that flame propagation would be inevitable. Limited amounts of smoke was present at all times, and these quantities appeared to diminish as the fire burned longer. The smoke came to the surface through minute crevices and apertures, and at times appeared to be a belching action. Whenever the surface was disturbed, much larger quantities of smoke were apparent. Because of the lack of oxygen for complete combustion of the material, samples of the smoke at the surface level were taken to determine the carbon monoxide concentrations being generated. In eight different tests made at different locations on the cell, the largest concentration in any one test was .1%.

Initial control and extinguishment of small fires could be accomplished as stated in Fire Test No. Five. Because of the availability of the milled material being produced, it was felt that extinguishment by smothering, using this material as the smothering agent could be a possibility. A full load of approximately twenty two yards was dumped on the cell and was spread by a bladed tractor over an area 15 ft x 50 ft. This took place approximately four hours after ignition. The cover varied in depth from six to twelve inches. When the covering was completed, the area showed no visible indications of fire or smoke. After a time lapse of approximately thirty minutes, smoke issued from the covered area in isolated spots. Three hours later the entire covered area was again involved in fire. No merit could be fixed to this method of extinguishment. Final extinguishment of the involved cell was accomplished using two one and one eighth inch straight stream nozzles each having a nozzle pressure of fifty p.s.i.

These two nozzles were flowed for a period of two hours at which time complete extinguishment was attained. The method of operation was to place both lines at the windward end of the cell and work slowly across the top of the cell. It was very obvious when complete extinguishment had been attained in an area so that lines could be advanced. No difficulty in extinguishment was experienced in any one section over another. Complete soaking of the burning layer of material was essential for extinguishment. There appeared to be very little run off of water from the cell during the extinguishment process.

Because all facets of this report are still under study by the Madison Fire Department, no recommendations relative to methods of safe storage have been made at this time. Studies of the hazards involved in the milling process will have to be made to determine any degree of severity.

Respectfully submitted,

Captain Vincent J. Geier

Captain Vincent J. Geier,
Superintendent of Training,
Madison Fire Department

DATE: October 3, 1969

VIII-B - Blowing, Odor, Esthetics

111

BLOWING

Blowing litter has been one of the most persuasive objections to some of Madison's sanitary landfill operations for unprocessed refuse (Figure 111). The extent of the problem depends on wind direction and speed as well as exposure of the working face to the wind. For example, unprocessed refuse dumped at one of Madison's other landfills may be caught by the wind immediately and blown over the boundary fence. On occasion, special work details have been sent out on Saturdays to pick up litter from the lawns of homes near landfills. In 1969 alone, some $22,000 was spent for manpower to control and pick up blowing paper from landfills. Even 15-foot-high movable fences placed downwind from the working face have failed to solve the blowing problem associated with landfilling unprocessed refuse.

As noted elsewhere in this report, various grate sizes and hammer patterns were used to obtain a particle size which would reduce blowing problems at the landfill. With properly ground milled refuse, the blowing problem was found to be minimal. Madison's Director of Public Works has stated that this feature alone justifies a milled refuse operation. Landfilling has been carried out with milled refuse during winds up to 60 mph on a flat site with only minor problems. Those blowing problems that are experienced are usually due to sheets of plastic, which are not thoroughly shredded in the mill and therefore tend to roll across the fill surface. Such items do not become airborne, and are readily caught by low fences.

Three factors may be given to explain the lack of blowing of milled refuse. First, particles of milled refuse tend to become entangled in each other so that they are disharged in clumps rather than as individual particles which can be blown away. Second, the small surface area of individual particles of milled refuse provide a small target for the wind. This is in contrast to a page of newsprint which, caught in a high wind, acts like a sail and blows for long distances. Observations at the landfill site have confirmed that bits of freshly milled refuse blow only a few feet before coming to rest. Finally, in a landfill, a crust similar to papier mache over the surface of milled refuse in a few weeks.

ODOR

The Olin Avenue Landfill is bounded by a playfield on one side, residential areas on two sides, and the Dane County Coliseum on the other. The Coliseum is a 10,000-seat facility. Thus, there was a large "audience" available to make known their complaints if any odor problems developed. Fortunately, no such problems have occurred.

Lack of unpleasant smells is one of the most notable features mentioned by visitors to the milled refuse landfill areas. Project personnel theorize that ready access to air and the accompanying drying of the surface of the milled refuse cells produce an aerobic buffer zone which infiltrates odors produced deeper in the cells. In support of this theory, it was noted that by digging 3 to 6 inches into a cell, one begins to detect odor typical of decaying refuse. Upon digging a foot or more, a most disagreeable odor is produced.

Some minor odor problems have developed during unusually wet periods when, due to improper drainage of depressions between the test cells, ponds of water formed. These problems have been readily solved by filling the low areas or by providing drainage channels.

ESTHETICS

Milled refuse is relatively homogeneous and looks like oversized confetti. Viewed from a distance, milled refuse is nondescript and unobnoxious since it contains no large recognizable items. Of the thousands of lay people who have viewed the Olin Avenue Landfill, no one has objected to the sight of uncovered milled refuse.

IX. EUROPEAN OBSERVATIONS

INTRODUCTION

The proctice of milling or pulverizing solid waste for landfill disposal has only recently been introduced into the United States. Other than the few grinders found in composting plants and bulky waste reduction facilities, this country has had little or no experience with the machinery involved in milling. Aside from the Madison operation, in which both authors are involved, even less experience is available on placing milled refuse in a landfill.

In contrast to the situation in the United States, the literature suggests that pulverizing solid wastes for landfilling without daily cover is accepted and widely used in Europe. In fact, documents citing European experience with this method are largely responsible for the concept being implemented at Madison and, more recently, at other United States installations. Among beneficial features of milled refuse cited in these documents are the increased density of milled refuse, the ability to operate a landfill without nuisance or hazard to the surrounding area, the lack of need for daily soil cover, and improved acceptance by the public of milled over unprocessed refuse in land disposal.

The Refuse Milling Project at Madison - representing the combined efforts of the City of Madison, the University of Wisconsin-Madison, the Heil Company of Milwaukee, and the Environmental Protection Agency - has as its goals: evaluation of the economics and equipment of a refuse mill, evaluation of milled refuse itself, and evaluation of milled refuse used in landfill. Five years of operating experience, practical field evaluations, and detailed studies dealing with specific aspects of the milling facility and the landfill have resulted from this project. Most questions about transferring European observations to this country and about the acceptability of the concept in the United States have been answered adequately. The only major questions remaining concern long-term results at the landfill site and transfer of information developed at Madison to other locations having different refuse compositions, climates, and operating conditions. It was apparent to the authors that the quickest way to gather information on these broad questions was to review the experiences of European refuse milling installations, emphasizing those which place the milled product in a landfill for disposal.

On May 31, 1972, the authors departed on a 27-day study tour of European refuse milling installations during which 22 sites (Appendix O) were visited and discussions were held with 27 persons having broad experience in the design and evaluation of milling facilities and milled refuse landfills. Because of the ease of communication, the many references in the literature, and the long-term use of milled refuse for landfill in the United Kingdom, it was decided to spend a major portion of the tour in Great Britain, Accordingly, 18 person were interviewed and 11 sites visited during the 10 days spent in England and

Scotland. This portion of the tour was arranged by Messrs. Sumner and Green of the Department of the Environment Offices in London, based on their extensive experience with solid waste management throughout the United Kingdom. The tour was balanced by including both operating and regulatory personnel as well as machinery representatives of major manufacturers. Installations known to be trouble free, and others known to have problems of some sort, were included.

Three persons were extensively interviewed and five sites (plus one unprocessed refuse fill) were visited in France. Although solid waste milling is widely practiced in France, the lack of both time and direct communication cut our stay in that country. The French sites were chosen by the authors based on the literature and personal contacts.

As refuse milling for landfill disposal does not appear to be as widely practiced in Germany or Switzerland as in England and France, only two milled refuse sites and three persons were visited in each country. One unprocessed refuse fill, picked on the basis of its reputation as a good "sanitary landfill", was also visited in each country. The milling sites were selected through personal contacts andliterature references. The unprocessed refuse landfills were selected after discussions with a city engineer in Germany and a federal official in Switzerland.

The milled refuse sites visited in the United Kingdom, France, Germany, and Switzerland represent only a fraction of the number of installations in these countries, and an even smaller fraction of such installations throughout all of Europe. Our estimate of the number of installations in those countries visited alone is 150, where nearly all of them landfill all or a major fraction of the milled refuse produced. This figure is based largely on lists of installations supplied by major equipment manufacturers.

Indications are that those sites visited provided a realistic cross-section of all the installations. Further, much of the information obtained during the latter portion of the study tour was repetitious of earlier visits. Finally, and most importantly, the knowledge of many of the persons interviewed extended beyond one site, or even one country. For example, in England, France, and Switzerland time was spent with federal and regulatory personnel who had broad knowledge of installations in their countries and elsewhere and could talk with authority about the successes and problems experienced. Also, time was spent with representatives of equipment manufacturers who were acquainted in detail with installations of their manufacture throughout Europe. These people were particularly candid in their remarks about landfilling milled refuse, and were quick to point out where in their opinion problems had been experienced and the reasons for such problems.

PROCEDURE

Typical site visits and interviews were conducted in the following manner. Almost without exception the chief administrator of refuse disposal activities, usually at the equivalent level of Director of Public Works in the United States, was informed about the impending visit. The contact was made by a representative of the manufacturer of the equipment in use or by national governmental officials. An equipment representative was present during approximately half of the site visits to act as interpreter and/or to provide an introduction to the people to be interviewed. In addition, the representatives commonly provided background information on the installation to be visited and unusual or important features to be noted during the visit.

The administrator or his appointee was first provided a copy of a paper written recently by the authors describing the Madison refuse reduction project.* This was done to establish quickly that the visitors were knowledgeable in the practice of refuse milling and to initiate communication with the person being interviewed. Otherwise, no information about experiences at Madison was volunteered until near the close of the interview. The purpose of this procedure was to insure that discussions represented the administrator's true opinion of his operation and the milling concept in general.

A copy of the proposed outline for this report was provided to the person being interviewed to act as a guide for discussion and to make the point immediately that the purpose of this visit was to learn about the landfill, not the equipment. The point was made that it is the landfill which is of most concern in the United States and that the purpose of the trip was to learn from their experience in operating such a landfill. It commonly took 2 to 3 hours to discuss the points A through I in the outline, after which a tour of the installation was made, usually taking another 1 to 2 hours.

The purpose of the tour was to look for negative aspects of the operation, often to the surprise and perhaps dismay of the person being interviewed. Thus, the site visits amounted to hunts for flaws in the landfill, whether they be signs of rodents or insects, odors, blowing papers, leachate problems, or others. It is significant to note not only that were most persons tolerant of the rather negative questioning, emphasizing problems rather than successes, but also that they often seemed to be amused or bewildered by some of the questions dealing with matters which to them were not an issue worth discussing. For example, the presence of a few flies on the landfills on some occasions was always acknowledged; however, the level was felt to be so low as not to warrant any concern on their part and certainly not to be an issue for detailed discussion with foreign visitors.

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*Ham, R. K., W. K. Porter, and J. J. Reinhardt. Refuse milling for landfill disposal. Pt. 1. Public Works, 102(12):42-47, Dec. 1971

Ham, Porter, and Rienhardt. pt. 2. Public Works, 103(1):70:72, Jan. 1972.

Ham, Porter, and Reinhardt. pt. 3. Public Works, 103(2):49-54, Feb. 1972.

RESULTS AND DISCUSSION

It must be remembered that the results cited in this section are based on observations made during one visit to a small fraction of the total number of European installations which landfill milled refuse and to an even smaller fraction of the people having experience in the subject. Remember, also, that comments in this report are not meant to be derogatory or fault-finding with respect to regulatory agencies or facility designers or operators. In most cases, where problems were apparent, the persons responsible were well aware of the situation but, due to factors beyond their control, were unable to deal with them. Each person and site visited is listed by name in Appendix O. A summary of the observations made during each visit is listed separately, arranged in arbitrary order, A through U.

Several general observations may be made. First, there was often a disturbing difference between the actual operations of a milling-landfill facility and the potential of that facility. Modern well-designed plants with good equipment were available, and adequate and sometimes over-adequate staffing was provided. However, the landfill disposal of the milled refuse was often poorly planned and/or operated. Quite often, only simple changes would be necessary to improve the site greatly. This lack of follow-through at most sites was disturbing, although it aided the purposes of the study tour, because problem sources could be documented and applied to other installations.

A second general observation is that the concept of using milled refuse in landfills without daily cover has developed on the basis of operating experience and not on the basis of controlled testing. What is known about landfilling milled refuse has come from a few innovative landfill managers who have undertaken some basic evaluations on their own initiative with virtually no financial support. Such innovative methods without exhaustive testing move technology forward and soon provide experience to document advantages and disadvantages of a system. However, it seems reasonable to expect that persons involved with the new methods would be in close contact with others in similar situations, especially if additional costs are associated with the new technique, and that there would be a genuine concern for any actual or potential disadvantages associated with their system. Perhaps the fact that such concern was not widely evident attests to the acceptability of the concept of using milled refuse for landfill an one of the proven methods for solid waste disposal.

The third overall comment is the general satisfaction with milling refuse prior to landfill as a method of handling solid waste. Although problems were evident at nearly every site, and even though there was often an apparent lack of concern or resources to optimize the operation or to understand all of its implications, there was widespread satisfaction with the landfilling of milled refuse. Most of the persons interviewed had experience with other methods for disposing of solid wastes, including land disposal, and were convinced that the use of milled refuse provided good, nuisance-free operations on a daily basis. Problems in obtaining cover soil, operating a site in wet weather, overcoming objections by nearby residents, conserving landfill volume, and obtaining permission from various agencies for unprocessed refuse disposal sites were cited over and over as having been solved with the use of milled refuse. The people were pleased with their operation and there was little or no thought of changing it, other than minor site improvements, etc.

The final comment is the apparent lack of true sanitary landfills - as defined in the theoretical United States standard, with daily cover, nuisance-free operation, etc - in areas visited. As in this country, there were usually a few sites, cited over and over in each country, where a sanitary landfill is being run. These are evidently well-known as being among the few good unprocessed refuse disposal sites. There were many reasons given, however, why such an ideal system would not work at the particular site being visited, including a lack of available space where unprocessed refuse could be landfilled without political problems, a lack of cover, or objections by the public or by planning or regulatory authorities. Thus, it was not unusual to hear of open dumping being used for the smaller disposal operations (less than 10,000 population); milled refuse landfilling for 10,000 to 100,000 population operations; composting where there is use for the compost; sanitary landfilling for the few large municipalities with adequate sites and cover; and incineration for the great majority of the population centers over 100,000 which have no suitable disposal sites nearby. In practice, then, the alternatives to milling seem to be open dumping for the smaller municipalities and incineration for the larger ones, except in unusual cases where a demand for compost exists, or where the financial resources, amounts of refuse, and suitable sites exist for sanitary landfilling. Those sanitary landfill sites visited on this tour, some of which were well-known in the area, were comparable to average or below-average sanitary landfill practice in the United States.

The remainder of this section provides the results of the tour of milled refuse landfills, arranged by subject.

Soil Cover:

In no case was daily cover applied to milled refuse landfills, nor did anyone think cover was needed as part of normal operations. In contrast, all persons expressed the opinion that frequent (but not necessarily daily) cover was required to run an unprocessed refuse landfill properly.

Most people stated that periodic cover would be desirable for milled refuse landfills located close enough to houses for residents to identify rejects or unmillable objects. It was felt that milled refuse would appear objectionable to persons within approximately 300 feet of a site, and that frequent cover would preclude problems of this sort. The only reason cited for covering milled landfills was an esthetic consideration, however. All persons visited believed that a final soil cover was necessary upon completion of a milled refuse site, again for reasons of esthetics. It was agreed that less cover was necessary over milled than unprocessed refuse because of the relative ease of leveling milled refuse.

There was some feeling that final cover is unnecessary in remote areas because in 3 to 5 years considerable vegetation covers milled refuse sites and the milled refuse itself degrades to the point that it looks much like soil, except for plastics and rags. Several such landfills were viewed, ranging in age up to 10 years (and in one case to 20 years). No problems were noted due to lack of final cover, nor were any cited by local officials. The presence of plastics and cloth might be objectionable for some final uses, though.

Odor:

Odor problems were observed and/or cited by local officials only when conditions were present which would normally make the site unacceptable with burning, as at one site where unprocessed refuse was burning underground in part of a milled refuse landfill. There the milled refuse fill was built over an open dump that had an underground fire which could not be extinguished. At other sites mill rejects and/or bulky items were on fire for various reasons. Other cases are cited in section D on fires, but the point is that any fire is unacceptable and will lead to odors.

Another cause of odors was the unfortunate practice of landfilling dead animals, process rejects, unprocessed refuse, septic tank pumpings, and bulky items at milled refuse sites and not covering these materials with either soil or milled refuse. In the few instances where such materials with either soil or milled refuse. In the few instances where such materials were promptly covered with milled refuse, no odor was detected. It is obvious that unplanned placement of unprocessed refuse at a milled refusessite destroys the integrity of the site and obviates advantages gained by using milled refuse, unless these materials are compacted and covered immediately.

There were a few cases in which milled refuse was dumped into standing water; some of the refuse was exposed to the atmosphere. Local odors were observed at these locations. The ponding of surface water on milled refuse - another potential source of odor - was also noted, although no unusual levels of odor could be traced to this source on the day of visit.

Odor levels above those at other milled refuse sites were detected at landfills using drum pulverizers to mill refuse. Two factors are thought to account for increased odor levels at these sites. First, water is normally added to incoming refuse so the rotating drum can more easily abrade the material. Therefore, the refuse is abnormally wet at time of placement. Second, the milled refuse product from such pulverizers is very coarse. For example, in the milled product from such plants we observed whole potatoes, large pieces of fruit and other garbage matter, which will rot and produce odor just like unprocessed refuse.

The final source of odor was poor housekeeping in the milling plant itself, especially at the feed end. Cases were noted where significant amounts of incoming refuse were left in the open for long periods, in some instances for several days. Daily cleanup of the plant, including the raw refuse storage and handling areas, is necessary to avoid undue odor in the plant.

Aside from the situations discussed above, odor was not a problem at milled refuse landfills visited, nor was odor a cause for concern by local officials. All stated that odor levels are significantly below those experienced in landfilling unprocessed refuse, even when daily cover is provided. The odor which is present is mild and sweetish, something like silage, and is usually noticed only on the fill itself and more particularly on active parts of the fill. Once one moves several feet away from the refuse, or onto milled refuse more than a few weeks old, no odor is discernible.

Blowing Debris:

The use of milled refuse in European landfills has not avoided all problems of blowing debris normally associated with refuse disposal operations. There is no assurance that blowing will not be experienced just because refuse is milled. A problem can arise from too large a particle size, lack of site management and planning, improper disposal of rejects, etc.

There was considerable evidence gathered by observation during visits, and amplified by talks with local and regulatory authroities, to show that milled refuse exhibits a definitely reduced tendency to blow when compared with unprocessed refuse. Many sites were visited where both unprocessed and milled refuse were landfilled, and invariably the blown debris around those sites was primarily unprocessed refuse. On several occasions both unprocessed refuse and milled refuse were being landfilled on the day of the visit, and pictures were taken which clearly show the difference in the amount of blowing debris. Blowing was observed to be dependent on particle size. The least blowing debris was observed on sites milling refuse with a Gondard mill equipped with a 55 mm grate opening, which resulted in the finest grind encountered.

Film plastics - not properly shredded by any mill observed - and in a few cases large pieces of paper - seemingly unaffected by certain mills - blew to some extent. Thus, the fences, shrubbery, or trees around virtually all sites visited do collect some blowing debris. Note in this regard that nearly all blowing matter that had been milled was caught in grass or on the lower poetions of any fencing, trees, or shrubs immediately adjacent to the site.

One unnecessary source of debris on many sites visited resulted from the method of transporting milled refuse to the landfill. When milled refuse was carried in open-top containers, often filled to overflowing, over rough roads at relatively high rates of speed, a trail of refuse was often strewn along the roadway. Since such roadways were entirely on site, the debris was probably not a true public nuisance, but it did lead to an untidy operation.

Fire:

The possibility of fire is a constant concern of responsible landfill operators. One of the principal reasons for providing daily soil cover in landfills of unprocessed refuse is to partition the refuse into sections, sealing it off from the atmosphere to minimize fire potential. Evidence gathered during the study tour indicates that a properly run milled refuse landfill still represents a fire potential, although the likelihood of fire, and its extent if one does occur, is greatly reduced. The most common cause of fires cited was vandals igniting unprocessed refuse dumped with milled refuse.

There were two types of fires observed with milled refuse. First, milled refuse is capable of supporting combustion where a flame front spreads across the surface and burns combustible material projecting above the maché mat of the fill surface. The seriousness of such blazes depend on weather and compactness of the refuse. A fire of this type will not generally burn into the surface of the refuse mass. It is readily extinguished with water or by using a tractor either to scrape off the top burning layer of refuse or to cover it with milled refuse or soil. Surface fires appeared to occur once or twice a year on the average at the sites visited.

The second type of fire occurs when milled refuse is banked so steeply that it is loose and relatively uncompacted. Once combustion takes place in this situation, it can slowly penetrate into the bank. If not controlled, a fire of this type can in time spread to the entire bank, climb to the top of the landfill, and work across the surface.

Landfills on the study tour which had steep banks also had an increased tendency to burn. One site provided an unbelievable example of how milled refuse can burn. The site was located in a pit perhaps 20 to 30 feet deep. The milled refuse was piled haphazardly around the site but concentrated around one-half of the pit wall. Evidently, refuse was trucked to the edge and dumped; whatever angle of repose was attained was left undisturbed.

Little if any compaction was provided. A layer of milled refuse of unknown depth was placed across much of the bottom of the pit, but not leveled out.

On the day of the visit virtually all the fill **faces** on the entire site were smoldering. A small pile of several hundred pounds of unprocessed refuse was in flames in the center of the site, near the mill itself. The **plant** operators indicated that the fire had been burning for two years and that it had been set by a highly placed person with responsibility for the site. Furthermore, since this person had never asked **that** the fire be put out, it had been allowed to burn freely for the entire two years, as site personnel had no authority to extinguish it.

What began as a day of comedy turned out to be one of the most valuable days of the tour. Upon closer examination, nearly all of the fire was **observed** to have remained on the steep, uncompacted slope. There were no active flames to be seen on the milled refuse, even on the slope. At the bottom of the slope **the** fire had burned out a small gully, approximately a foot deep and 2 to 3 feet wide, in the milled refuse which had been spread across the floor. Since the gully was directly at the bottom of the slope, there probably had been little or no compaction. Combustion had hardly affected the bottom of the site except for this gully.

The burning penetrated the slope in "fingers" perhaps a yard long, making the edge of the bank almost inaccessible. The combustion had worked its way from the incline as much as 10 feet across the top of the refuse and was still smoldering in some places. In these areas the penetration beneath the surface was perhaps an inch.

This site substantiated what had been observed on a smaller scale at other sites: milled refuse will smolder and burn, especially on steeply inclined faces and other places where the refuse is loose and uncompacted. Note, however, that even after burning uncontrolled for two years, it was not judged to be a **major** hazard or nuisance.

Practically all fires reported at other sites began with the burning of unprocessed refuse which had been landfilled with the milled material and not covered. Most of the fires were started by vandals in bulky items which were not milled. Unfortunately, bulky or unprocessed items were often dumped at the bottom of an incline of milled refuse, and fires starting in these objects were ideally located to burn at least the inclined face of the milled refuse. Other materials which served as a basis for fires included milling rejects in the case of the Tollemache and Gondard mills, industrial wastes which were not milled, and unprocessed refuse which for some reason was landfilled along with the milled refuse. Reasons for the presence of unprocessed refuse included lack of sufficient milling capacity, machinery repairs, multiple use of a site by organizations not connected with the milling facility, and lack of site planning and management.

Vectors or Animal Infestation:

Flies, rats, and birds were taken to indicate possible vector problems.

When questions were asked at each site about fly problems, the response was normally one of surprise that the **topic** had been brought up. It seems that the fly problem is generally considered nonexistent on milled refuse and **therefore** hardly worth discussing. Common responses were that some flies canbbe found on recently milled refuse, but that virtually no flies are present on refuse older than six months. In either case, the ambient fly population in surrounding areas is approximately the same as on the landfill. It was mentioned several times that tall grass or a freshly plowed field will result in much greater fly populations than will milled refuse.

Increased fly populations were observed **in cases** where a portion of the refuse either was not milled, as in the case of bulky refuse, or **was** adequately milled, as when whole food items were present in the milled product. The addition of water to refuse entering a wet-drum pulverizer (which seemed to allow such items as whole potatoes to pass through undamaged) undoubtedly served to boost the fly population also. Another likely place for flies was on inclined faces where the refuse was highly accessible. Fly populations were held to a minimum where only milled refuse of reasonably fine grind was exposed to the atmosphere and where the refuse was shaped into smooth, even contours. Note that even under the worst conditions experienced, however, fly **problems** were considered to be minimal and always an improvement over landfills of unprocessed refuse, even with "daily" **cover**. It should also be noted that good daily cleanup and periodic spraying with insecticide was seen to be necessary at the feed end of the milling facilities.

Rodents were said to exist at several sites visited, although only an occasional rabbit was observed **during** the tour. Sites with rats had some unprocessed refuse, or else a rat population was present on or near the site before milled refuse was placed. Such sites were typically near surface waters, had steep earth slopes, or were near farms. In one case, for example, there was reportedly a mass exodus of rats from a nearby farm to the milled refuse landfill when a change was made in the farming method; however, soon afterwards the rats moved back to the farm, supposedly choosing to adapt to the new farming practices rather than to the milled refuse landfill.

Except for **two** sites, there were no signs of rat activity directly on the milled refuse. Even at these two sites only signs sugh as test burrows and fecal matter were seen. Both sites were above-grade fills which had steep and uneven sides and were surrounded by much vegetation. There was also some volunteer vegetation on the refuse near the burrows. In one case, the lower portion of the mound of refuse contained unprocessed material which had been covered with soil and capped with milled refuse. The burrows appeared to be at or near the junction between the milled and unprocessed refuse and went through the cover dirt to whatever was below. In the other case, the part of the mound where burrows were observed **had** been used for the open dumping of ballistically rejected refuse. Not only did this practice result in uncontrolled fire and unnecessary odors, but it also evidently attracted a rodent population.

Only one person, of all those interviewed, felt that rats were eating milled refuse. He had no proof of this possibility, and his opinion was contradicted by many others.

There was some confusion as to the exact species of rodents at sites where rats were said to exist. For example, in several cases rabbit droppings, or large burrows capable of being used by rabbits, were observed. It is thought that these might have been mistaken for signs of rat activity. There also were several species of animals which were locally referred to as rats, but which did not fit the descriptions of Norway or Roof rats at all.

Rodent problems were uniformly believed to be reduced with milled refuse, and except for improper site management or previously existing populations, such problems were virtually nonexistent. Several officials did arrange for a rodent-control officer to inspect their sites periodically and do some routine poisoning. This was done as a precautionary and public relations measure, particularly in cases where a site was near a populated area or where rodent concentrations existed prior to use of the site for milled refuse disposal.

In contrast to minimal rodent and insect infestation, birds were commonly cited as being present on milled refuse landfills. Seagulls, drawn primarily by the warmth of the refuse, are common on milled landfills during winter, while small birds are predominant during warmer weather. There was considerable division of opinion as to whether birds obtain food from milled refuse. Most people seemed to think that the large birds do not eat milled refuse, although they will pick at it. The real debate, however, concerned the small, seed-eating birds. There is a distinct possibility that small birds can find bits of food in freshly milled refuse in addition to seeds, earth worms, and crawling insects in older milled refuse. Several persons said that they had observed small birds eating from milled refuse, while others said that these birds pick at the refuse but do not eat. Birds were commonly present on milled refuse landfills, especially in areas where the refuse was no more than 2 to 3 days old. The observation was made by several people that once milled refuse is more than several days old it loses much of its attractiveness to birds.

In no instance was the bird population at a site considered a problem, but the opinion was expressed a number of times that birds could be a potential problem at sites near airports. It was commonly pointed out that similar bird populations are found in many situations, such as a freshly plowed field, and that no complaints had been received about birds. It was also noted that bird populations were no higher and normally less than those on landfills of unprocessed refuse.

Leachate and Gas:

Very little information was available on leachate or gas generation. In most instances these were not considered to be problems; hence, no information had been gathered and no testing performed.

Leachate seemed to be of some concern in Germany, where groundwaters are widely used for water supply. It is in Germany that some of the most rigorous studies on leachate generation are taking place, although few, if any, of these studies relate to the effect of milling refuse on leachate generation.

Several sites were found where ground or surface waters were under surveillance for signs of refuse leaching. Several wells or test wells were being monitored for this purpose, but no effect had been noticed. This result must be accepted cautiously, however, for some of the wells were significant distances(up to a half mile) away from the landfill, others were placed with no apparent knowledge of the hydrogeology of the area so that they could be at the wrong location and/or the wrong depth, and still others may not have been in place long enough for leachate to reach the well. At one site, test wells were located immediately adjacent to and surrounding a sizeable portion of the landfill. No degradation of ground water had been observed.

Two sites were located in gullies or abandoned railroad cuttings which were underdrained in such a manner that surface runoff from the refuse or any leachate generated bytthe refuse would flow down the gully into small streams a short distance away. Samples of water leaving the toe of the refuse, which was placed in about 20 foot lifts, were analyzed by river authorities, in each case with no apparent adverse results. Other samples of surface water had been taken on an informal basis at several other sites, again with no consequential results.

Two special tests on leachate generation carried out in specially designed facilities outside the landfill were described. In one case, two small boxes, one containing milled and the other unprocessed refuse, were subjected to outdoor weather conditions. Leachate was produced but, because of the difference in refuse composition and quantity, the results were difficult to compare and translate into practical terms. At the EAWAG facility in Switzerland, special leachate test bins had been constructed and filled with milled refuse which had been composted to a low degree, crude refuse, and incinerator residue, respectively. The results indicated that the most contaminants were produced by the milled refuse composted to a low degree and the least by the incinerator residue. The investigator had reason to doubt the validity of the results because of noncomparable selection of the refuse and incinerator residue, and is currently pursuing a much larger, more controlled study.

At the location where milled refuse from another site is to be landfilled, a clay berm will be placed between the refuse and the adjacent river. Any leachate collected by this berm or wall will be treated by some undisclosed means. Note, also, that at this site negotiations are presently underway to set up special test beds to compare leachate production of milled and unprocessed refuse.

In summary, there seemed to be little concern about leachate and gas production. Tests which were conducted on the subject were performed by a few perceptive individuals who, unfortunately, did not have the resources to do a complete study, or by regulatory agencies who were monitoring readily available water samples from surface runoff and nearby wells. It appears that much more data will be available in a few years, especially from Germany, where the pro and con schoold of thought on milling are gathering evidence to support their views. Since the purpose of the study tour was to look at ongoing refuse milling installations, and not to provide a review of European literature on the subject, further discussionoof the German studies is beyond the scope of this report.

Site Design and Operation:

There were no obvious, uniformly applied site design and operation criteria in use at the sites visited. Perhaps this should be expected, as a representative sample of both good and bad sites were visited. Some sites were dumping in water, other were on fire. Some sites were remote, others were surrounded by homes. At some sites only milled refuse was landfilled, at others crude refuse was open dumped alongside the milled refuse.

From the wide variety of sites visited, there evolved some definite criteria which in the authors' opinion should be applied to site design and operation. They are:

1. If anything but milled refuse is to be landfilled at the site, it should be compacted and covered immediately;
2. Milled refuse should be placed and spread in a manner to provide smooth surfaces. It is essential to avoid steep inclines which are relatively uncompacted and present a rough surface. Slopes should never exceed four feet horizontal to one foot vertical.
3. Daily and final soil cover is not necessary except for esthetic reasons. Several persons suggested, but no site practiced, the routine daily covering of milled refuse for sites close to (say, within 300 feet of) homes, schools, or other populated areas. Most persons felt that final cover was desirable for all but a few remote locations.

4. The site should have a low fence or some other barrier to restrict blowing debris and to keep out the public as much as possible.
5. No refuse, whether it is milled or not, should be dumped in bodies of surface water.
6. A supply of cover dirt, or an alternative site, should be available in case of milling equipment failure.
7. Diversion of runoff away from the site should be promoted by proper contouring of the refuse and the surrounding area. Depressions in the refuse should be avoided.
8. The same site planning and engineering design used on a conventional sanitary landfill should be applied to a milled refuse site.

Density and Settlement:

The density of milled refuse in a landfill is of special significance and therefore will be treated separately. It was somewhat disconcerting to hear repeated references to the savings of landfill space by using milled refuse when compared with unprocessed refuse, yet to find so little documentation of the actual savings achieved. Estimates ranging from 20 to 50 percent reduction in initial refuse volume as a result of milling were quoted, but often the figures did not relate to landfill conditions. At one site, for example, the primary reason given for milling was to reduce the volume of refuse so higher tonnages of refuse could be transported per barge loaded to volumetric capacity. Based on extensive testing, an increase in density of at least 60 percent but more probably 100 percent over the density of unprocessed refuse was projected by milling, where this increase would be attained with refuse loosely packed, being compressed only by its own weight in the barge.

In several cases, small scale box tests were run to quantify volume reduction through milling. At one site, bales were made of milled and unprocessed refuse, similar in composition and under identical compaction. The results were:

Unprocessed refuse prior to baling	242 lbs./cu. yd
Unprocessed refuse after baling	433 lbs./cy. yd
Milled refuse after baling	919 lbs./cu. yd

This suggests a volume savings of over 50 percent in a landfill if milled rather than unprocessed refuse is landfilled. The densities are lower than commonly experienced in United States landfills, but the significant savings found in the test suggests that there would be considerable savings, if not the full 50 percent, under United States conditions.

At two other sites, boxes of one cubic meter were constructed and filled with milled and unprocessed refuse. The changing levels of refuse in the boxes were then monitored over several years. The results showed that milled refuse was more dense than unprocessed and that the volume occupied by the milled refuse dropped steadily with time. It is difficult to use these **findings** in landfill design, however, because refuse composition and moisture content were not determined and, in one case, unequal and unknown weights of refuse were placed in the milled and unprocessed refuse boxes. Furthermore, since no compaction was applied, the results do not reflect what happens in a landfill but more properly relate to the density during transport to the site.

Perhaps the **best** landfill test results at a site were **obtained** when refuse was dug from the landfill and weighed. The in-place volume was estimated by backfilling the hole with a known volume of sugar sand. Such a test is subject to certain problems and errors, but the results did indicate approximately a 30 percent increase in density by using milled refuse in landfills.

All persons agreed that milling of refuse would result in a savings of landfill space. Theddiscrepancy was not whether such a savings existed but what actual change in density could be expected. Note in this regard that much smaller equipment than that used in United States landfills was observed in most European installations. It is felt that the difference in landfill density between milled and unprocessed refuse would be greater when lighter machines are used for compaction, so one must be careful in transferring data on density generated elsewhere to the United States.

Settlement of milled refuse was invariably described as uniform, providing unprocessed materials such as bulky items were well compacted or were not present in the fill. This observation was borne out by site inspections where, except in obvious cases of poor initial leveling at some sites, older sites were seen to retain a uniform and even surface. Although all persons interviewed stated that milled refuse settled more uniformly than unprocessed refuse, this comparison could not be confirmed by visits to the sites on this particular itinerary.

Little information was available on the other aspect of settlement: namely, the total amount of settling to be expected with milled as opposed to unprocessed refuse, and the relative rates of settling. Several persons felt that settlement would be 3 to 4 times faster with milled refuse, where a milled refuse landfill will be nearly completely settled five **years** after placement in comparison to **15 to 20 years** for unprocessed refuse to reach the same degree of stability. Of course, the actual figures would vary widely depending on many factors, but most of the persons citing these or similar **figures** gathered them as a result of years of experience. Thus, although the actual figures may vary, and even though most of the persons interviewed had no data to back up **their** remarks, it was commonly asserted that milled refuse landfill will become stable with respect to settlement in less time than will unprocessed refuse.

What little that was known about total settling of milled refuse seemed to come from the small boxes cited earlier in the discussion on refuse density. Because of problems translating the results to an actual landfill, however, these results are difficult to apply accurately to the question of ultimate settlement and will not be discussed further.

A final major consideration in site design is whether the milled refuse landfill should be constructed in uncompacted layers no more than three feet thick which are allowed to stabilize for 3 to 6 months before the next layer is applied, or whether much thicker compacted lifts should be used. In the latter case, the refuse will take longer to decompose and will undergo somewhat uniform degradation. In the former case, the fill is virtually stabilized as it is constructed, because more rapid decomposition occurs close to the refuse surface. Another way of accomplishing this same goal is to allow milled refuse to compost in windrows prior to landfilling. Depending on which of these two methods, or some modification of them, is chosen, the design of a site would be quite different. For example, if the choice is to decompose refuse quickly in thin layers, the refuse should be dumped as loosely as possible and no compaction should be provided. All traffic should be diverted around the area until the refuse is stabilized and ready to accept the next layer. At this point the refuse should be compacted and traffic run over it as much as possible to achieve the highest possible density.

The authors are not prepared to make any recommendations as to which method is better. There are believers in both alternatives, and sites are being operated at both extremes and at many levels in between. It seems useful to point out that there are various ways of operating a milled refuse landfill and that this is one area that deserves much study.

Public Acceptance:

Along with savings in landfill volume, increased public acceptance was typically given as a major reason why refuse was being milled at the various sites visited. The fact that the public was more willing to accept a milled than unprocessed refuse landfill was never disputed throughout the tour. It appears, however, that public opinion was usually based more on emotion than on evidence which convinced them that milled refuse would be less obnoxious than unprocessed refuse. In the United Kingdom, for example, the public seems to consider incinerator residue and milled refuse together under the term "treated refuse", and of course, treated refuse has to be better than untreated refuse.

The presentation of a fictitious but reasonable example in the United States will serve to illustrate the point. Suppose that a new site is needed for refuse disposal for a population of insufficient size to support an incinerator and that land disposal is the only viable method available. After a site has been secured, application is made to the Planning Authority, which has virtually complete control of refuse disposal, both from a standpoint of planning and of regulation. If local opposition to the proposed site arises prior to required public hearings, the concept of using "treated", or in this case milled, refuse can be introduced as a compromise. The application may then be approved subject to the requirement that mostly milled refuse, or perhaps only milled refuse, be landfilled at that site. Several sites were visited where milled refuse was offered as a compromise to obtain a site.

Of interest to this report is whether permission to use a site with milled refuse is based on sound technical advice and/or adequate experience. The decision makers do have a technical staff, and they can call on experts from around the country as well as from federal and other levels of government; however, the fact remains that the decision makers are elected and are generally not experts in matters related to solid wastes. They may or may not use the technical advice provided to them. Although there was some conflict of opinion between persons interviewed, there have been cases in which the Planning Authority did base its decision on the merits of landfilling milled refuse as opposed to unprocessed refuse. The fact that landfilling of milled refuse is gaining popularity and is now considered one of the ordinary methods of solid waste disposal - along with sanitary landfill, composting, and incineration - attests to the acceptance of the milled refuse concept by the public and, in turn, by planning authorities.

Finally, a question asked of every person interviewed was whether he knew of complaints registered by the public against landfills with milled refuse. In nearly all cases the response was no. In each instance where complaints had been received, they were easily traced to improper operation, as discussed earlier in the report, or to special site considerations not related to the use of milled refuse. Thus, local officials were pleased with the public acceptance of their operation and were in no case contemplating returning to the landfilling of unprocessed refuse.

Refuse Composition:

The only analyses found for refuse composition were European or national averages as quoted in texts, national surveys, and the like. No figures were obtained for any of the specific sites visited.

Information on the fraction of the refuse coming from residential, commercial, and industrial sources was **generally** available but too variable to be of interest here. While some sites had more or less corrugated than others, for instance, the refuse going into milling facilities appeared on the whole to be quite similar to refuse in the United States. It is unlikely that milled refuse will behave differently in the United States due to changes in the refuse composition alone.

A more significant difference is the larger amount of bulk material in U.S. refuse than in European solid waste. Although it is difficult to quantify the difference, there did appear to be fewer bulky items as well as less construction and demolition debris and lawn, tree, or shrub clippings at the European sites. Thus, a higher fraction of the refuse produced in Europe would seem to be millable than in the United States.

Material not milled at the sites visited was either sent to another landfill, often an open dump, or was disposed at the milled refuse site. Much has already been written about the hazards of the latter practice, so it will not be repeated here. A pronounced tendency toward the use of larger mills capable of handling a larger portion of the solid waste was noted. All of the **major mill** manufacturers seemed to have, or were planning to produce, larger mills capable of taking more bulky material, white goods, furniture, and the like.

SUMMARY

A tour of European refuse milling installations was made to document, and then relate to the United States, European experience in this method of handling solid wastes. Of particular interest was the landfilling of milled refuse without daily cover, a practice which has been in use up to 20 years in Europe.

Site visits to milled refuse landfills and **discussions** with knowledgeable persons focused on such matters as soil cover, odors, blowing debris, fire, vectors, leachate, gas, site design, density, settlement, public acceptance, and refuse composition.

It was concluded that milling refuse for disposal in a landfill did not cure all problems associated with land disposal of refuse. However, the practice is widely used and is accepted by administrators, regulatory agencies, and the public as an improved method of landfilling which does not require daily cover, except perhaps for aesthetic purposes.

ACKNOWLEDGEMENTS

The support of the University-Industry Research Program of the Graduate School at the University of Wisconsin and the National Center for Resource Recovery is gratefully acknowledged. Special thanks are due to the many people in Europe who graciously gave of their time, frequently after normal working hours, to meet with us, provide transportation, make appointments, etc., and to those who have reviewed this report. Complete copies of this report are available from:

The National Center For Resource Recovery
1211 Connecticut Avenue, N.W.
Washington, D.C. 20036

X. APPENDICES

A - Gondard Cost Calculations

The basic method used to make the cost calculations was to divide the annual cost for such items as labor, depreciation, and power by the projected annual tonnage milled. The annual projected tonnage was determined from the average work rate of the machine, the number of hours per day that the machine is operated, and an assumed 48 work weeks/year. It is assumed that the plant will be inoperative 4 weeks per year, 1-1/2 weeks due to legal holidays and 2-1/2 weeks due to down time for major repairs and maintenance. It is felt that computing costs on an annual basis is more reliable than any other method, such as per month. For example, labor costs, determined monthly, for a particular grate size may be penalized if a man was sick or on vacation, which is unrelated to the size of grate being used in the machine.

The only exception to the computation of costs on an annual basis was for the power cost. Since the grates in the mill were changed periodically in an effort to determine the optimum size, a particular set of grates was not in the mill for the same period as the billing from the power company. It was thus necessary to proportion the power consumption and tonnage milled during the experimental periods to one month, since utility bills are based on monthly consumption. The resultant utility cost was then divided by the monthly tonnage milled. It was not necessary to make this type of projection for other utilities since they are not dependent upon the grate size or tonnage milled by the machine.

A description is given below of the pertinent factors concerning each of the cost categories listed in the body of the report.

LABOR

The average annual labor rate for the plant operator, assistant plant operator, and maintenance man is \$7.20 + \$6.50 + \$5.45/hour, or \$19.15/hour. \$19.15/hour x 2,080 hours/year = \$39,830/year labor cost. Annual average labor wage rates are calculated in Appendix D and include all fringe benefits plus overtime. It is significant to note that inclusion of fringe benefits amounts to an hourly wage rate 30 percent higher than the basic wage rate. Inclusion of overtime with the fringe benefits results in a wage rate which is 50 percent greater than basic wage rate. The labor cost per ton on an average annual basis is then determined by dividing \$39,830 by the projected annual tonnage.

AMORTIZATION

The annual cost was determined by assuming a reasonable machinery life and interest rates depending upon the source of funds. The annual cost was divided by the projected annual tonnage milled. Land costs are excluded from the amortization costs. The following table lists the amortization data used to arrive at the annual amortization cost of $32,100 per year.

TABLE A-1

Depreciation Data

Cost Item	Original Cost	Estimated Life-Years	Interest Rate	Salvage Value	Annual Cost
Building	$133,100	20	5.8	$4,000	$11,300
Grinder and Conveyors	126,700	15	5.8	4,000	12,700
Scale	6,900	20	7.0	1,000	600
Front End Loader	15,400	8	7.0	3,000	2,300
Packer Trucks (2)	38,000	10	7.0	3,000	5,200
Total Annual Cost - Amortization					$32,100

POWER COST

As explained earlier, the experimental periods did not exactly coincide with the utility companies' billing periods. It was therefore necessary to project power consumption to a monthly basis in order to determine the equivalent monthly costs. This is so because power rate charges decrease with increasing usage. The following table lists the proportionate monthly costs and tonnage milled during the experimental runs. The costs of power ranging from $.34 to $.30 per ton are the weighted averages during the times that the three grate sizes were used.

TABLE A-2

"Actual" Power Costs for Feed Conveyors and Mill

Grate Size (Inches)	Time Period	Proportioned Monthly Cost	Proportioned Monthly Tons	Cost Per Ton
3-1/2	Sept. 18-Oct. 8, 1967	$ 295	828	$0.36
	Jan. 1-Feb. 1, 1968	298	744	0.40
	March 18-31, 1968	318	930	0.34
	April 1-21, 1968	316	956	0.33
4	July 1-28, 1968	312	984	0.32
	Weighted Average	$1,539	4,442	$0.34
5	May 14-June 2, 1968	326	1,224	0.26
	June 3-30, 1968*	318	1,187	0.27
	Sept. 16-20, 1968	301	967	0.31
	Sept. 30-Nov. 3, 1968	298	949	0.31
	Nov. 4-Dec. 1, 1968	294	930	0.32
	Dec. 2-29, 1968	283	773	0.36
	Weighted Average	$1,820	6,030	$0.30
6-1/4	Oct. 30-Nov. 19, 1967	293	1,012	0.29
	Dec. 11-31, 1967	280	735	0.38
	Feb. 2-March 17, 1968	277	780	0.36
	April 22-May 13, 1968	305	1,116	0.27
	July 29-Aug. 18, 1969	298	1,131	0.26
	Aug. 19-Sept. 15, 1968	296	1,060	0.28
	Weighted Average	$1,749	5,834	$0.30

* Excluding week of June 17-21 when private contractor loads were milled.

OTHER UTILITIES

It was not necessary to project the consumption of other utilities from the experimental period to one month because the water, lighting and gas heating costs were independent of the grate size used in the machine and the tonnage milled. Since these projections to monthly quantities were not needed, it is possible to total the utility bills on a calendar year basis and divide by the annual tonnage to arrive at the cost per ton. The lighting, water and gas heating costs for calendar year 1968 were totalled and the annual cost of $2,300, $200 and $1,200 is listed in the cost data section of the body of the report.

HAMMER WEAR

A more extensive report of the hammer wear costs and maintenance programs is contained in Appendix E. During most of the project, the life of a set of hammers was near 400 to 500 tons per set. Towards the end of the project, it was shown that daily resurfacing of the hammers could prolong the life of a set to 1,200 tons. It is based on the recent work that the lives and costs of hammer maintenance are estimated in Appendix E. Contrary to popular opinion, it should be noted that the magnitude of costs associated with hammer wear is relatively small compared to labor and amortization. The labor costs associated with hammer wear and maintenance is excluded from the hammer wear costs and is included with the labor costs.

MILL MAINTENANCE

Other maintenance costs for the mill besides hammers include the cost of: replacing grates; replacing wearable mill parts such as replaceable liners, shafts and spacers; and using oxygen and acetylene for cutting purposes. The major cost is for the replacement of grates, which is estimated to be necessary every 8,000 tons. These costs will probably fluctuate very little as indicated in the table of cost data in the body of the report.

SMALL EQUIPMENT

A detailed accounting of small equipment purchased during the last project year shows the total cost of such equipment to be

$800. This equipment includes such items as tools, a bench grinder, a vacuum cleaner, rubber belting and installation of a flame deflector. It is to be noted that purchases of this type are continuing in the third year of the project, and should not be written off as initial expenses.

GENERAL SUPPLIES

A detailed accounting of the general supplies during the last project year likewise indicates a total expenditure of $1,100. This expense is comprised of many small items including janitorial supplies and general supplies such as oil and small hardware expenses.

FRONT END LOADER OPERATION

The $500 listed in the table for the front end loader operation is the billing from the City of Madison Garage for maintenance done on the front end loader during one year. Note that the depreciation was previously included under the amortization cost.

OTHER COSTS

An accounting of the project expenses also reveals $1,700 of other miscellaneous-type expenses during the third project year. Included in these costs are items such as sheet metal, conveyor wiring, a chain for the speed reducer on the conveying equipment, repair of the scale, installation of new bearings, and seal coating the parking area.

ADJUSTED COSTS

There is a second table of costs in the body of the report which reflects what the cost of the present pilot plan operation might be if adequate hauling equipment could be found for the milled refuse. It is assumed the plant could be operated by two men, and the work scheduled so the plant was milling refuse 7 hours per day instead of the current 5.33 hours per day. In the table of adjusted costs per ton, the projected annual tonnage is higher than the tonnage figures in the preceding table because the plant is in operation for more hours per day. The other major change in the table of adjusted costs is that the labor cost is $28,000 instead of $39,830 because one man (the lowest paid) is no longer required at the plant. Other minor changes are that the power, hammer wear, mill maintenance, and front end loader operation costs will increase above the actual situation due to the additional tonnage being milled.

TRANSPORTATION COSTS

Costs are also listed later in the body of the report for hauling of refuse from the plant to the landfill. These operating costs are described as transportation costs and so are considered independently of the plant operating costs. An accounting of the billing from the City of Madison Garage reveals the expenses listed in Section III-A, Tables 3 and 4 .

B - Gondard Projected Annual Tonnage

In order to compute costs per ton on the basis of annual cost and annual tonnage, it is necessary to project the annual tonnage that could be pulverized if one grate were used continuously in the mill for one year. Computation of cost per ton on an annual basis is felt to be much more reliable than computing on a shorter basis such as per month. Use of a short time period may not accurately indicate the effects of vacations and major repairs during which time the plant may be shut down.

The projected annual tonnage is based on the most current production capability of the machine, the number of hours per day that the machine is operated (based on previous experience), and on an estimated number of working weeks per year. Since rubber cleats were placed on the conveyors feeding refuse to the mill, it has been found that the production rate has increased. More recent experience has verified that it is reasonable to assume the overall production rates with the 3-1/2 inch grate will be 8.4 tons per hour; and will be 9.0 tons per hour with the 5-inch grate; and will be 9.4 tons per hour with the 6-1/4 inch grate. The overall production rate is used because it includes down time due to conveyor jams of the mill. Thus, use of the overall production rate with the actual hours that the machine is milling refuse should reflect accurately the tonnage that can be milled in one year when one size grate is used continuously.

Eight months of detailed scrutiny of the operating records of the plant revealed that the machine is actually milling refuse for 5.33 hours per 8-hour working day. The remainder of the time is spent on clean-up, getting ready for the day's operation, shut down for necessary repair of trucks, lunch, and lapse between arrival of first load of refuse and start of milling operations.

Since the plant operates 5 days per week, the only other figure needed to project annual tonnage is the number of weeks the plant is in operation per year. City of Madison employees receive 7.5 days of legal holidays per year which is the same as 1-1/2 weeks. It is further assumed that the plant will be shut down for major repairs and alterations for an additional 2-1/2 weeks per year. Although the pilot plant has been shut down more frequently than 2-1/2 weeks per year, it is felt that correct initial design and scheduling of maintenance could reduce the down time to 2-1/2 weeks per year. Thus, the 2-1/2 weeks for shutdown for major repair plus 1-1/2 weeks' vacation amounts to 4 weeks per year that the plant is not in operation.

The projected annual tonnage for the three grate sizes is then:

3-1/2 Inch Grate -

$$\frac{8.4 \text{ tons}}{\text{hour}} \times \frac{5.33 \text{ hrs}}{\text{day}} \times \frac{5 \text{ days}}{\text{week}} \times \frac{48 \text{ wks}}{\text{year}} = 10{,}750 \text{ tons/year}$$

5-Inch Grate -

$$\frac{9.0 \text{ tons}}{\text{hour}} \times 5.33 \times 5 \times 48 = 11{,}500 \text{ tons/year}$$

6-1/4 Inch Grate -

$$\frac{9.4 \text{ tons}}{\text{hour}} \times 5.33 \times 5 \times 48 = 12{,}050 \text{ tons/year}$$

C - Summary Data From Gondard Experimental Runs

The following sheets summarize the data obtained during each of the Gondard experimental runs. Data were kept each day of plant operations on the quantities of refuse received at the landfill, the portion milled, and the portion bypassed around the plant. The daily operating records also indicate the time that the plant was operating, the minute the plant was shut down, the length of shutdown, and the reason for shutdown, such as refuse truck being full. In addition, daily records were kept of work times in the plant, the compaction equipment operator's time in the landfill, cover dirt usage and utility consumption. It is this daily information that is summarized on the sheets contained in this appendix.

TABLE C. Summaries of Experimental Runs.

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 3-1/2-IN. GRATES - FALL 1967
September 18 - October 6, 1967

Plant Performance

		Rate	Overall Rate
Tons Milled	534		
Milling Time	77.9 hours		
Down Time	11.4 hours		
Total Time	89.3 hours		
Average Production Rates - Tons per Hour			
Milled		6.6	5.8
Rejected		0.2	0.2
Total		6.8	6.0

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,167
Total Milled - Tons	534
Total Unprocessed - Tons	633
Total Large Items & Brush (considered separately) 257 Loads - Tons	122
Total No. of Loads of Refuse Received at Site	346
Total No. of Loads Milled	157
Percentage of Total Loads which are Milled	45%

Work Times

Man-Hours of Milling - 77.9 hours x 3 men =	234 man-hours
Total Man-Hours in Plant	378
Man-Hours of Compaction (1 man)	
ManMilled - Man-Hours	18.4
Unprocessed - Man-Hours	33.0
Total Man-Hours for Compaction Equipment Operator	133.5

Landfill

Milled	
Tons	534
Equipment Time - Hours	18.4
Equipment Time - (Hours) per Hundred Tons	3.4
Unprocessed	
Tons	633
Equipment Time - Hours	33.0
Cover Dirt - Cubic Yards	1,190
Equipment Time - (Hours) per Hundred Tons	5.2
Cover Dirt - Yards per Ton	1.9

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	6,060
440 Volt Electrical Service - Kilowatt Hours	8,160
Gas - Hundred of Cubic Feet	135
Water - Cubic Feet	3,775
Load Lugger - Miles	241
Frond End Loader - Hours	10.2

TABLE C (Cont.)

Table C (Cont)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 2-IN. GRATES - FALL 1967
October 9-27, 1967

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	450		
Milling Time	75.1 hours		
Down Time	7.9 hours		
Total Time	83.0 hours		
Average Production Rates - Tons per Hour			
Milled		5.6	5.1
Rejected		0.4	0.3
Total		5.0	5.4

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,073
Total Milled - Tons	450
Total Unprocessed - Tons	623
Total Large Items & Brush (considered separately) 257 Loads - Tons	72
Total No. of Loads of Refuse Received at Site	363
Total No. of Loads Milled	129
Percentage of Total Loads which are Milled	36%

Work Times

Man-Hours of Milling - 77.9 hours x 3 men	225.3 man-hours
Total Man-Hours in Plant	399.5
Man-Hours of Compaction (1 man)	
Milled - Man-Hours	20.7
Unprocessed - Man-Hours	35.9
Total Man-Hours for Compaction Equipment Operator	124.0

Landfill

Milled	
Tons	450
Equipment Time - Hours	20.7
Equipment Time - (Hours) per Hundred Tons	4.6
Unprocessed	
Tons	623
Equipment Time - Hours	35.9
Cover Dirt - Cubic Yards	1,180 for 402 tons
Equipment Time - (Hours) per Hundred Tons	5.8
Cover Dirt - Yards per Ton	2.9

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	4,520
440 Volt Electrical Service - Kilowatt Hours	8,480
Gas - Hundred of Cubic Feet	1,106
Water - Cubic Feet	4,235
Load Lugger - Miles	93
Frond End Loader - Hours	8.4
Packer No. 411 - Miles	15

TABLE C (Cont.)

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 6-1/4 IN. GRATES - FALL 1967
October 30 - November 17, 1967

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	703		
Milling Time	75.7 hours		
Down Time	7.6 hours		
Total Time	83.8 hours		
Average Production Rates - Tons per Hour			
Milled		9.1	8.2
Rejected		0.2	0.2
Total		9.3	8.4

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,165
Total Milled - Tons	703
Total Unprocessed - Tons	462
Total Large Items & Brush (considered separately) 257 Loads - Tons	82
Total No. of Loads of Refuse Received at Site	375
Total No. of Loads Milled	195
Percentage of Total Loads which are Milled	52%

Work Times

Man-Hours of Milling - 75.7 hours x 3 men	227.1 man-hours
Total Man-Hours in Plant	399.5
Man-Hours of Compaction (1 man)	
Milled - Man-Hours	29.6
Unprocessed - Man-Hours	35.5
Total Man-Hours for Compaction Equipment Operator	131.5

Landfill

Milled	
Tons	703
Equipment Time - Hours	29.6
Equipment Time - (Hours) per Hundred Tons	4.2
Unprocessed	
Tons	462
Equipment Time - Hours	35.5
Cover Dirt - Cubic Yards	1,030 for 683.20 tons
Equipment Time - (Hours) per Hundred Tons	7.7
Cover Dirt - Yards per Ton	1.5

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	5,500
440 Volt Electrical Service - Kilowatt Hours	7,680
Gas - Hundred of Cubic Feet	2,011
Water - Cubic Feet	4,000
Load Lugger - Miles	111
Frond End Loader - Hours	10.2

TABLE C (Cont.)

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED GARBAGE - 6-1/4-IN. GRATE - EARLY WINTER 1967-68
November 20 - December 1, 1967

Plant Performance		Operating Rate	Overall Rate
Tons Milled	103		
Milling Time	6.9 hours		
Down Time	2.6 hours		
Total Time	9.5 hours		
Average Production Rates - Tons per Hour			
Milled		14.9	10.8
Rejected		--	--
Total		14.9	10.8

Refuse Quantities	
Total Milled - Tons	103
Total No. of Loads Milled	40

Work Times	
Man-Hours of Milling - 3 men x 9.5 hours	28.5 man-hours
Total Man-Hours in Plant (including 119.7 man-hours spent milling 311 tons of rubbish)	402 man-hours
Man-Hours of Compaction (1 man)	--
Milled - Man-Hours	--
Unprocessed - Man-Hours	--
Total Man-Hours for Compaction Equipment Operator	--

Landfill	
Milled	
Tons	89
Equipment Time - Hours	--
Equipment Time - (Hours) per Hundred Tons	--
Unprocessed	
Tons	44
Equipment Time - Hours	--
Cover Dirt - Cubic Yards	90
Equipment Time - (Hours) per Hundred Tons	--
Cover Dirt - Yards per Ton	2.0

Utility and Equipment Usage (For 3 weeks of milling 311 tons of rubbish and 103 tons of garbage)	
220 Volt Electrical Service - Kilowatt Hours	5,260
440 Volt Electrical Service - Kilowatt Hours	5,600
Gas - Hundred of Cubic Feet	232.8
Water - Cubic Feet	2,976
Load Lugger - Miles	127
Frond End Loader - Hours	8.7

TABLE C (Cont.)

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED SEPARATED RUBBISH - 6-1/4 IN. GRATE - WINTER 1967-68
November 27 - December 8, 1967

Plant Performance		Operating Rate	Overall Rate
Tons Milled	311		
Milling Time	38.2 hours		
Down Time	1.7 hours		
Total Time	39.9 hours		
Average Production Rates - Tons per Hour			
Milled		7.9	7.6
Rejected		0.2	0.2
Total		8.1	7.8

Refuse Quantities	
Total Milled - Tons	311
Total No. of Loads Milled	91

Work Times	
Man-Hours of Milling - 3 men x 3919 hours	119.8 man-hours
Total Man-Hours in Plant (including 28.5 man-hours spent milling 103 tons of garbage	402
Man-Hours of Compaction	
Milled - Man-Hours	9.2
Unprocessed - Man-Hours	--
Total Man-Hours for Compaction Equipment Operator	127

Landfill	
Milled	
Tons	311
Equipment Time - Hours (7.3 man-hours)	264 tons
Equipment Time - (Hours) per Hundred Tons	2.8
Unprocessed	
Tons	
Equipment Time - Hours	
Cover Dirt - Cubic Yards	
Equipment Time - (Hours) per Hundred Tons	
Cover Dirt - Yards per Ton	

Utility and Equipment Usage (For 3 weeks on milling 311 tons of rubbish and 103 tons of garbage)	
220 Volt Electrical Service - Kilowatt Hours	5,260
440 Volt Electrical Service - Kilowatt Hours	5,600
Gas - Hundred of Cubic Feet	232.8
Water - Cubic Feet	2,976
Load Lugger - Miles	127
Frond End Loader - Hours	8.7

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 6-1/4 IN. GRATE - WINTER 1967-68
December 11-29, 1967

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	474		
Milling Time	70.0 hours		
Down Time	1.8 hours		
Total Time	71.8 hours		
Average Production Rates - Tons per Hour			
Milled		6.7	6.5
Rejected		0.1	0.1
Total		6.8	6.6

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons		975
Total Milled - Tons		474
Total Unprocessed - Tons		501
Total Large Items & Brush (considered separately)	374 Loads	27
Total No. of Loads of Refuse Received at Site		374
Total No. of Loads Milled		152
Percentage of Total Loads which are Milled		40%

Work Times

Man-Hours of Milling - 3 men x 72.8 hours	218.4 man-hours
Total Man-Hours in Plant	381 man-hours
Man-Hours of Compaction	
Milled - Man-Hours	16.4
Unprocessed - Man-Hours	--
Total Man-Hours for Compaction Equipment Operator	127

Landfill

Milled	
Tons	474
Equipment Time - Hours	17.1
Equipment Time - (Hours) per Hundred Tons	3.6
Unprocessed	
Tons	
Equipment Time - Hours	
Cover Dirt - Cubic Yards	
Equipment Time - (Hours) per Hundred Tons	
Cover Dirt - Yards per Ton	

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	5,280
440 Volt Electrical Service - Kilowatt Hours	5,600
Gas - Hundred of Cubic Feet	165
Water - Cubic Feet	3,053
Load Lugger - Miles	113
Frond End Loader - Hours	7.2

TABLE C (Cont.)

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 3-1/2-IN. GRATE - WINTER 1967-68
January 2 - February 1, 1968

Plant Performance		Operating Rate	Overall Rate
Tons Milled	689		
Milling Time	98.6 hours		
Down Time	2.7 hours		
Total Time	101.3 hours		
Average Production Rates - Tons per Hour			
Milled		6.8	6.6
Rejected		0.2	0.2
Total		7.0	6.8

Refuse Quantities	
Total Quantity of Combined Refuse from all Wards - Tons	1,496
Total Milled - Tons	689
Total Unprocessed - Tons	807
Total Large Items & Brush (considered separately)	64
Total No. of Loads of Refuse Received at Site	540
Total No. of Loads Milled	223
Percentage of Total Loads which are Milled	40%

Work Times	
Man-Hours of Milling - 3 men x 98.6 hours	296 man-hours
Total Man-Hours in Plant	686
Man-Hours of Compaction	206
Milled	27
Unprocessed	56
Total Man-Hours for Compaction Equipment Operator	

Landfill	
Milled	
Tons	689
Equipment Time - Hours	27
Equipment Time - (Hours) per Hundred Tons	3.9
Unprocessed	
Tons	504 (as of Feb. 1)
Equipment Time - Hours	56
Cover Dirt - Cubic Yards	450 (incomplete)
Equipment Time - (Hours) per Hundred Tons	11.1
Cover Dirt - Yards per Ton (Cubic)	0.9 (incomplete)

Utility and Equipment Usage	
220 Volt Electrical Service - Kilowatt Hours	8,820
440 Volt Electrical Service - Kilowatt Hours	10,080
Gas - Hundred of Cubic Feet	389.1
Water - Cubic Feet	4,439
Load Lugger - Miles	129
Frond End Loader - Hours	30.9

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 6-1/4 IN. GRATE - WINTER 1967-68
February 2 - March 15, 1968

Plant Performance		Operating Rate	Overall Rate
Tons Milled	830		
Milling Time	108.4 hours		
Down Time	6.5 hours		
Total Time	114.9 hours		
Average Production Rates - Tons per Hour			
Milled		7.6	7.1
Rejected		0.1	0.1
Total		7.7	7.2

Refuse Quantities	
Total Quantity of Combined Refuse from all Wards - Tons	1,795
Total Milled - Tons	830
Total Unprocessed - Tons	565
Total Large Items & Brush (considered separately) - Tons	45
Total No. of Loads of Refuse Received at Site	746
Total No. of Loads Milled	283
Percentage of Total Loads which are Milled	38%

Work Times	
Man-Hours of Milling - 108 hours x 3 men	324
Total Man-Hours in Plant	818
Man-Hours of Compaction	
Milled	32
Unprocessed	121
Total Man-Hours for Compaction Equipment Operator	278

Landfill	
Milled	
Tons	844
Equipment Time - Hours	31.8
Equipment Time - (Hours) per Hundred Tons	3.8
Unprocessed	
Tons	1,456
Equipment Time - Hours	177.1
Cover Dirt - Cubic Yards	2,880
Equipment Time - (Hours) per Hundred Tons	12.2
Cover Dirt - Yards per Ton	2.0

Utility and Equipment Usage	
220 Volt Electrical Service - Kilowatt Hours	14,620
440 Volt Electrical Service - Kilowatt Hours	8,800
Gas - Hundred of Cubic Feet	393.1
Water - Cubic Feet	6,512
Load Lugger - Miles	158
Frond End Loader - Hours	46

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 3-1/2-IN. GRATE - LATE WINTER 1967-68
March 18-29, 1968

		Operating Rate	Overall Rate
Plant Performance			
Tons Milled	343		
Milling Time	48.3 hours		
Down Time	1.3 hours		
Total Time	49.6 hours		
Average Production Rates - Tons per Hour			
Total		7.1	6.9
Refuse Quantities			
Total Quantity of Combined Refuse from all Wards - Tons			705
Total Milled - Tons			343
Total Unprocessed - Tons			362
Total Large Items & Brush (considered separately) - Tons			25
Total No. of Loads of Refuse Received at Site			263
Total No. of Loads Milled			97
Percentage of Total Loads which are Milled			37%
Work Times			
Man-Hours of Milling - 48 hours x 3 men		144	
Total Man-Hours in Plant		270	
Man-Hours of Compaction			
Milled		no record kept	
Unprocessed		no record kept	
Total Man-Hours for Compaction Equipment Operator		84	
Landfill			
Milled			
Tons		319	
Equipment Time - Hours		no record kept	
Equipment Time - (Hours) per Hundred Tons		not available	
Unprocessed			
Tons		197	
Equipment Time - Hours		no record kept	
Cover Dirt - Cubic Yards		580	
Equipment Time - (Hours) per Hundred Tons		not available	
Cover Dirt - Yards per Ton		2.9	
Utility and Equipment Usage			
220 Volt Electrical Service - Kilowatt Hours		4,380	
440 Volt Electrical Service - Kilowatt Hours		4,960	
Gas - Hundred of Cubic Feet		60.5	
Water - Cubic Feet		2,924	
Load Lugger - Miles		27	
Frond End Loader - Hours		15.0	

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 3-1/2 IN. GRATE - SPRING 1968
April 1968

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	617		
Milling Time	87.2 hours		
Down Time	2.2 hours		
Total Time	89.4 hours		
Average Production Rates - Tons per Hour			
Total		7.1	6.9

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,231
Total Milled - Tons	617
Total Unprocessed - Tons	614
Total Large Items & Brush (considered separately)	38
Total No. of Loads of Refuse Received at Site	440
Total No. of Loads Milled	129
Percentage of Total Loads which are Milled	30%

Work Times

Man-Hours of Milling - 87 hours x 3 men	261
Total Man-Hours in Plant	395
Man-Hours of Compaction	
Milled	22
Unprocessed	63
Total Man-Hours for Compaction Equipment Operator	127

Landfill

Milled	
Tons	617
Equipment Time - Hours	22.3
Equipment Time - (Hours) per Hundred Tons	3.6
Unprocessed	
Tons	614
Equipment Time - Hours	62.7
Cover Dirt - Cubic Yards	cell not complete
Equipment Time - (Hours) per Hundred Tons	10.2
Cover Dirt - Yards per Ton	cell not complete

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	7,800
440 Volt Electrical Service - Kilowatt Hours	8,480
Gas - Cubic Feet	13,700
Water - Cubic Feet	3,154
Load Lugger - Miles	65
Frond End Loader - Hours	14.3

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 6-1/4 IN. GRATE - SPRING 1968
April 22 - May 13, 1968

Plant Performance			
Tons Milled	775		
Milling Time	95.5 hours		
Down Time	2.3 hours		
Total Time	97.8 hours	Operating Rate	Overall Rate
Average Production Rates - Tons per Hour			
Total		8.1	7.9
Refuse Quantities			
Total Quantity of Combined Refuse from all Wards - Tons			1,384
Total Milled - Tons			775
Total Unprocessed - Tons			609
Total No. of Loads of Refuse Received at Site			448
Total No. of Loads Milled			229
Percentage of Total Loads which are Milled			50%
Work Times			
Man-Hours of Milling - 94 hours x 3 men		282	
Total Man-Hours in Plant		484	
Man-Hours of Compaction			
Milled		25	
Unprocessed		31	
Total Man-Hours for Compaction Equipment Operator		134	
Landfill			
Milled			
Tons		739	
Equipment Time - Hours		25	
Equipment Time - (Hours) per Hundred Tons		3.4	
Unprocessed (April 1 - May 13, 1968)			
Tons		939	
Equipment Time - Hours		94	
Cover Dirt - Cubic Yards		cell not complete	
Equipment Time - (Hours) per Hundred Tons		10.0	
Cover Dirt - Yards per Ton		cell not complete	
Utility and Equipment Usage			
220 Volt Electrical Service - Kilowatt Hours		6,940	
440 Volt Electrical Service - Kilowatt Hours		8,160	
Gas - Cubic Feet		14,600	
Water - Cubic Feet		3,446	
Load Lugger - Miles		50	
Frond End Loader - Hours		5.9	

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 5-IN. GRATE - SPRING 1968
May 14-31, 1968

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	733		
Milling Time	88.8 hours		
Down Time	5.1 hours		
Total Time	93.9 hours		
Average Production Rates - Tons per Hour			
Total		8.2	7.8

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,257
Total Milled - Tons	733
Total Unprocessed - Tons	524
Total Large Items & Brush (considered separately)	
Total No. of Loads of Refuse Received at Site	410
Total No. of Loads Milled	218
Percentage of Total Loads which are Milled	53%

Work Times

Man-Hours of Milling - 89 hours x 3 men	267
Total Man-Hours in Plant	451
Man-Hours of Compaction	
Milled	28
Unprocessed	29
Total Man-Hours for Compaction Equipment Operator	109

Landfill

Milled	
Tons	733
Equipment Time - Hours	27.8
Equipment Time - (Hours) per Hundred Tons	3.8
Unprocessed	
Tons	1,268
Equipment Time - Hours	123.7
Cover Dirt - Cubic Yards	1,870
Equipment Time - (Hours) per Hundred Tons	9.8
Cover Dirt - Yards per Ton	1.5

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	5,480
440 Volt Electrical Service - Kilowatt Hours	8,640
Gas - Cubic Feet (Hundreds)	3
Water - Cubic Feet	3,114
Load Lugger - Miles	17
Frond End Loader - Hours	12

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 5-IN. GRATE - SUMMER 1968
June 3-23, 1968*

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	766		
Milling Time	93.0 hours		
Down Time	3.2 hours		
Total Time	96.2 hours		
Average Production Rates - Tons per Hour			
Total		8.2	8.0

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,924
Total Milled - Tons	766
Total Unprocessed - Tons	1,158
Total No. of Loads of Refuse Received at Site	589
Total No. of Loads Milled	210
Percentage of Total Loads which are Milled	36%

Work Times

Man-Hours of Milling - 93 hours x 3 men	279
Total Man-Hours in Plant	406
Man-Hours of Compaction	
Milled	19
Unprocessed	--
Total Man-Hours for Compaction Equipment Operator	123

Landfill

Milled	
Tons	499
Equipment Time - Hours	19.3
Equipment Time - (Hours) per Hundred Tons	3.9
Unprocessed	
Tons	not completed - see summary sheet for July 29 through August 16
Equipment Time - Hours	
Cover Dirt - Cubic Yards	
Equipment Time - (Hours) per Hundred Tons	
Cover Dirt - Yards per Ton	

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	6,880
440 Volt Electrical Service - Kilowatt Hours	9,920
Gas - Cubic Feet (Hundreds)	6
Water - Cubic Feet	3,629
Load Lugger - Miles	11
Frond End Loader - Hours	8.4

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*Excluded week of June 17-21 during which contract haulers' loads were milled.

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 3-1/2 IN. GRATE - SUMMER 1968
July 1-26, 1968*

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	635		
Milling Time	79.3 hours		
Down Time	2.8 hours		
Total Time	82.1 hours		
Average Production Rates - Tons per Hour			
Total		8.0	7.7

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,311
Total Milled - Tons	635
Total Unprocessed - Tons	676
Total No. of Loads of Refuse Received at Site	--
Total No. of Loads Milled	--
Percentage of Total Loads which are Milled	--

Work Times

Man-Hours of Milling - 79.3 hours x 3 men	238
Total Man-Hours in Plant	450
Man-Hours of Compaction	
Milled	20
Unprocessed	0
Total Man-Hours for Compaction Equipment Operator	128

Landfill

Milled	
Tons	430
Equipment Time - Hours	19.7
Equipment Time - (Hours) per Hundred Tons	4.6
Unprocessed	
Tons	not complete-
Equipment Time - Hours	see summary
Cover Dirt - Cubic Yards	sheet for July 29
Equipment Time - (Hours) per Hundred Tons	through
Cover Dirt - Yards per Ton	August 16

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	4,400
440 Volt Electrical Service - Kilowatt Hours	8,160
Gas - Cubic Feet (Hundreds)	3
Water - Cubic Feet	2,259
Load Lugger - Miles	108
Frond End Loader - Hours	18.3

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*Excluding week of July 22-28 when a mixed set of 4-inch and 5-inch grates were in the mill.

TABLE C (Cont.)

SUMMARY OF EXPERIMENTAL RUN
MILLED COMBINED REFUSE - 6-1/4-IN. GRATE - SUMMER 1968
July 29 - August 16, 1968

Plant Performance

		Operating Rate	Overall Rate
Tons Milled	775 (including August 19 and 20)		
Milling Time	88.8 hours		
Down Time	2.5 hours		
Total Time	91.3 hours		
Average Production Rates - Tons per Hour			
Total		8.7	8.5

Refuse Quantities

Total Quantity of Combined Refuse from all Wards - Tons	1,312
Total Milled - Tons	677
Total Unprocessed - Tons	635
Total No. of Loads of Refuse Received at Site	386
Total No. of Loads Milled	185
Percentage of Total Loads which are Milled	48%

Work Times

Man-Hours of Milling - 88.8 hours x 3 men	266
Total Man-Hours in Plant	413
Man-Hours of Compaction	
Milled	29
Unprocessed	57
Total Man-Hours for Compaction Equipment Operator	127

Landfill

Milled		
Tons	709	
Equipment Time - Hours	17.9	(for 443 tons)
Equipment Time - (Hours) per Hundred Tons	4.0	
Unprocessed		
Tons	548	
Equipment Time - Hours	39.6	(for 362 tons)
Cover Dirt - Cubic Yards	1,010	
Equipment Time - (Hours) per Hundred Tons	10.9	
Cover Dirt - Yards per Ton	1.8	

Utility and Equipment Usage

220 Volt Electrical Service - Kilowatt Hours	4,040
440 Volt Electrical Service - Kilowatt Hours	6,560
Gas - Cubic Feet (Hundreds)	3
Water - Cubic Feet	2,226
Load Lugger - Miles	14
Front End Loader - Hours	7.5

TABLE C (Cont.)

MONTHLY SUMMARY - AUGUST 1968
MILLED COMBINED REFUSE - 6-1/4-IN. GRATE
August 19 - September 13

Plant Performance		
Tons Milled	538	
Milling Time	66.2 hours	
Down Time	2.6 hours	
Overall Time	68.8 hours	
Production Rate - Tons per Hour		
Operating Rate	8.1	
Overall Rate	7.8	
Refuse Quantities		
Total Tons of Combined Refuse - West Side		1,757
Tons Milled		538
Tons Unprocessed		1,219
Work Times		
Man-Hours of Milling - 66.2 hours x 3 men		199
Total Man-Hours in Plant		590
Man-Hours of Compaction		
Milled Cell		
Unprocessed Cell		no record
Total Man-Hours for Compaction Operator		176
Landfill		
Milled		
Tons		
Compaction Time - Hours		
Unprocessed		
Tons		
Compaction Time		
Cover Dirt - Cubic Yards		
Utility and Equipment Usage		
220 Volt Electrical - Kilowatt Hours		4,080
440 Volt Electrical - Kilowatt Hours		5,440
Gas - Hundreds of Cubic Feet		5
Water - Cubic Feet		2,160
Front End Loader - Hours		8.3

TABLE C (Cont.)

MONTHLY SUMMARY - SEPTEMBER 1968
MILLED COMBINED REFUSE - 125 MM GRATE
September 16-27

Plant Performance		
Tons Milled	357	
Milling Time	45.8 hours	
Down Time	1.9 hours	
Overall Time	47.7 hours	
Production Rate - Tons per Hour		
Operating Rate	7.8	
Overall Rate	7.5	
Refuse Quantities		
Total Tons of Combined Refuse - West Side		870
Tons Milled		357
Tons Unprocessed		513
Work Times		
Man-Hours of Milling - 45.8 hours x 3 men		137
Total Man-Hours in Plant		268
Man-Hours of Compaction		no record
Milled Cell		
Unprocessed Cell		
Total Man-Hours for Compaction Operator		91
Landfill		
Milled		
Tons		
Compaction Time - Hours		
Unprocessed		
Tons		
Compaction Time		
Cover Dirt - Cubic Yards		
Utility and Equipment Usage		
220 Volt Electrical - Kilowatt Hours		2,420
440 Volt Electrical - Kilowatt Hours		4,100
Gas - Hundreds of Cubic Feet		4
Water - Cubic Feet		790
Front End Loader - Hours		11.1

TABLE C (Cont.)

MONTHLY SUMMARY - OCTOBER 1968
MILLED COMBINED REFUSE - 5-IN. GRATE
September 30 - November 1

Plant Performance

Tons Milled	1,010
Milling Time	126.5 hours
Down Time	5.5 hours
Overall Time	132.0 hours
Production Rate - Tons per Hour	
Operating Rate	8.0
Overall Rate	7.6

Refuse Quantities

Total Tons of Combined Refuse - West Side	1,974
Tons Milled	1,010
Tons Unprocessed	964

Work Times

Man-Hours of Milling - 126.5 hours x 3 men	380
Total Man-Hours in Plant	702
Man-Hours of Compaction	no record
Milled Cell	
Unprocessed Cell	
Total Man-Hours for Compaction Operator	228

Landfill

Milled	
Tons	192
Compaction Time - Hours	not kept
Unprocessed	
Tons	687
Compaction Time	not kept
Cover Dirt - Cubic Yards	not yet covered

Utility and Equipment Usage

220 Volt Electrical - Kilowatt Hours	7,100
440 Volt Electrical - Kilowatt Hours	11,680
Gas - Hundreds of Cubic Feet	688
Water - Cubic Feet	2,845
Front End Loader - Hours	11.9

TABLE C (Cont.)

MONTHLY SUMMARY - NOVEMBER 1968
MILLED COMBINED REFUSE - 5-IN. GRATE
November 4-29

Plant Performance		
Tons Milled	554	
Milling Time	72.0 hours	
Down Time	3.3 hours	
Overall Time	75.3 hours	
Production Rate - Tons per Hour		
Operating Rate	7.7	
Overall Rate	7.4	
Refuse Quantities		
Total Tons of Combined Refuse - West Side		1,596
Tons Milled		557
Tons Unprocessed		1,039
Work Times		
Man-Hours of Milling - 72.0 hours x 3 men		216
Total Man-Hours in Plant		521
Man-Hours of Compaction		no record
Milled Cell		
Unprocessed Cell		
Total Man-Hours for Compaction Operator		156
Landfill		
Milled		
Tons		517
Compaction Time - Hours		not kept
Unprocessed		
Tons		1,046
Compaction Time		not kept
Cover Dirt - Cubic Yards		1,520 for 1,560 tons
Utility and Equipment Usage		
220 Volt Electrical - Kilowatt Hours		7,780
440 Volt Electrical - Kilowatt Hours		6,240
Gas - Hundreds of Cubic Feet		1,878
Water - Cubic Feet		2,142
Front End Loader - Hours		16

TABLE C (Cont.)

MONTHLY SUMMARY - DECEMBER 1968
MILLED COMBINED REFUSE - 5-IN. GRATE
December 2-27

Plant Performance

Tons Milled	625
Milling Time	90.4 hours
Down Time	2.9 hours
Overall Time	93.3 hours
Production Rate - Tons per Hour	
Operating Rate	6.9
Overall Rate	6.7

Refuse Quantities

Total Tons of Combined Refuse - West Side	1,401
Tons Milled	644
Tons Unprocessed	757

Work Times

Man-Hours of Milling - 90.4 hours x 3 men	271
Total Man-Hours in Plant	650
Man-Hours of Compaction	
Milled Cell	41
Unprocessed Cell	66
Total Man-Hours for Compaction Operator	190

Landfill

Milled	compaction trial with rubber-tired front end loader
Tons	644
Compaction Time - Hours	30.9 hours for 518 tons
Unprocessed	
Tons	757
Compaction Time	45.1 hours for 486 tons
Cover Dirt - Cubic Yards	

Utility and Equipment Usage

220 Volt Electrical - Kilowatt Hours	9,880
440 Volt Electrical - Kilowatt Hours	7,520
Gas - Hundreds of Cubic Feet	2,817
Water - Cubic Feet	3,414
Front End Loader - Hours	43.9

Table C (Cont.)

Monthly Summaries - 1969

	January 5 weeks	February 4 weeks	March 4 weeks	April 5 weeks	May 4 weeks
Refuse Quantities:					
Total Tons		1,285	1,317	2,367	2,021
Tons Not Milled		235	232	877	1,146
Tons Milled		1,050	1,085	1,490	875
Plant Performance:					
Tons Milled	402	1,050	1,085	1,490	875
Milling Time - Hours	60.7	128.7	123.9	160.9	82.4
Shutdown Time - Hours	4.1	4.0	5.6	6.1	6.2
Overall Time	64.8	132.7	129.5	167.0	88.6
Production Rate (tons/hr.)					
Operational	6.9	8.2	8.8	9.3	10.6
Overall	6.5	7.9	8.4	8.9	9.9
Grate Size Opening	5 in.	4 in.	4 in.	4 in.	4 in.

D - Wage Rates at Madison Refuse Reduction Plant During Gondard Evaluations

It has been found that the most reliable way to determine labor cost is to compute it on an annual basis, including fringe benefits and overtime. Use of basic wage rates, such as appear on payroll sheets, do not include all the fringe benefits that may accrue to having an employee on one's staff. For the purposes of this project, in which it was desired to know the variation of costs associated with different sized grates, it was found that use of labor costs obtained from the city sanitation division could not be used. It was not valid to use typical payroll information because the need for a substitute for vacation could unfairly increase the labor cost for a particular size of grate.

It was therefore felt that the most meaningful way to determine labor cost is to calculate the total annual wage including base pay, fringe benefits, substitute pay and overtime. The annual wage can then be divided by the number of work hours per year to arrive at an hourly wage (annual average). It should be noted that this type of accounting indicates that the fringe benefits paid to City of Madison employees amounts to 30 percent of their basic wage. When overtime is added with the fringe benefits, the annual average wage rate is 50 percent above the basic wage rate. It is felt that recognition of these high labor costs, which are not commonly reported in the literature, should be made when making comparisons. The following pages are computations made to determine the annual average hourly wage of the three men who work at the plant, plus the landfill equipment operator.

TABLE D. Wage Rates of Employees, Refuse Reduction Plant, Madison, Wisconsin (October 1, 1969)

WAGE RATE
(Including Base Pay, Fringe Benefits, Overtime and Substitute Pay)
Effective October 1, 1969

REFUSE REDUCTION PLANT OPERATOR - basic wage rate $4.7625/hour
20 days vacation per year
12 sick days per year
315 hours of overtime per year

Base Pay $4.7625/hour x 2,080 hours/year	$ 9,906
Overtime - 240 hours/year x $6.84/hour (time-and-a-half)	2,249
SUBTOTAL - Base Pay plus Overtime	$12,155
Social Security - 4.8% x $7,800	374
Retirement - 11.04% x $7,800	861
Life Insurance - over 40 years old $12,000 x $0.60/$1,000 x 12 months x 0.32/1.32 (city share)	21
Health - $17.19/month x 12 months	206
Workmen's Compensation (estimate based on two sources)	85
SUBTOTAL - Base Pay, Overtime and Fringe Benefits (hourly wage rate of base, overtime and fringe benefits is $13,702/2,080 hours = $6.59/hour)	$13,702
Vacation substitute - $5.00/hour x 20 days x 8 hours/day	800
Sick Days substitute - $5.00/hour x 12 days x 8 hours/day	480
TOTAL ANNUAL WAGE	$14,982

Hourly Wage (annual av.) $14,982/2,080 hours = $7.20/hour

TABLE D. (Cont.)

WAGE RATE
(Including Base Pay, Fringe Benefits, Overtime and Substitute Pay)
Effective October 1, 1969

EQUIPMENT OPERATOR III - basic wage rate $4.2375/hour
17.5 days vacation per year
12 sick days per year
315 hours of overtime per year

Base Pay $4.2375/hour x 2,080 hours/year	$ 8,814
Overtime - 175 hours/year x $6.09/hour (time-and-a-half)	2,003
SUBTOTAL - Base Pay plus Overtime	$10,817
Social Security - 4.8% x $7,800	374
Retirement - 11.04% x $7,800	861
Life Insurance (between 30 and 40 years old) $10,000 x $0.40/$1,000 x 12 months x 0.32/1.32 (city share)	12
Health - $17.19/month x 12 months	206
Workmen's Compensation (estimate based on two sources)	85
SUBTOTAL - Base Pay, Overtime and Fringe Benefits (hourly wage rate of base, overtime and fringe benefits is $12,355/2,080 hours = $5.94/hour)	$12,355
Vacation substitute - $5.00/hour x 17.5 days x 8 hours/day	700
Sick Days substitute - $5.00/hour x 12 days x 8 hours/day	480
TOTAL ANNUAL WAGE	$13,535

Hourly Wage (annual av.) $13,535/2,080 hours = $6.51/hour

TABLE D. (Cont.)

WAGE RATE
(Including Base Pay, Fringe Benefits, Overtime and Substitute Pay)
Effective October 1, 1969

PUBLIC WORKS MAINTENANCE MAN I - basic wage rate $3.45625/hour
12.5 days vacation per year
12 sick days per year
315 hours of overtime per year

Base Pay $3.45625/hour x 2,080 hours/year	$ 7,189
Overtime - 315 hours/year x $5.00/hour (time-and-a-half)	1,632
SUBTOTAL - Base Pay plus Overtime	$ 8,821
Social Security - 4.8% x $7,800	374
Retirement - 11.04% x $7,800	861
Life Insurance (under 30 years old) $8,000 x $0.20/$1,000 x 12 months x 0.32/1.32 (city share)	5
Health - $17.19/month x 12 months	206
Workmen's Compensation (estimate based on two sources)	85
SUBTOTAL - Base Pay, Overtime and Fringe Benefits (hourly wage rate of base, overtime and fringe benefits is $10,352/2,080 hours = $4.98/hour)	$10,352
Vacation substitute - $5.00/hour x 12.5 days x 8 hours/day	500
Sick Days substitute - $5.00/hour x 12 days x 8 hours/day	480
TOTAL ANNUAL WAGE	$11,332

Hourly Wage (annual av.) $11,332/2,080 hours = $5.45/hour

TABLE D. (Cont.)

WAGE RATE
(Including Base Pay, Fringe Benefits, Overtime and Substitute Pay)
Effective October 1, 1969

LANDFILL OPERATOR - basic wage rate $4.175/hour
20 days vacation per year
12 sick days per year
-- hours of overtime per year

Base Pay $4.175/hour x 2,080 hours/year	$ 8,684
Overtime - hours/year x $ /hour (time-and-a-half)	--
SUBTOTAL - Base Pay plus Overtime	$ 8,684
Social Security - 4.8% x $7,800	374
Retirement - 11.04% x $7,800	861
Life Insurance $9,000 x $0.60/$1,000 x 12 months x 0.32/1.32 (city share)	16
Health - $17.19/month x 12 months	206
Workmen's Compensation (estimate based on two sources)	85
SUBTOTAL - Base Pay, Overtime and Fringe Benefits (hourly wage rate of base, overtime and fringe benefits is $10,226/2,080 hours = $4.93/hour)	$10,226
Vacation substitute - $5.00/hour x 20 days x 8 hours/day	800
Sick Days substitute - $5.00/hour x 12 days x 8 hours/day	480
TOTAL ANNUAL WAGE	$11,506

Hourly Wage (annual av.) $11,506/2,080 hours = $5.53/hour

E - Gondard Hammer Wear and Costs

Results with 4-inch grates show a set of hammers can last 1,200 tons with daily hard facing, as necessary. Based on previous work, a set of hammers used with 5 and 6-1/4 inch grates will have a life calculated as follows:

4-inch grate: 1200 tons

Based on differences in production rates:

5-inch grate: $\frac{9.0-8.4}{8.4}$ tons/hour = 7.1% increase

1.071 x 1200 = 1285, or 1300 tons/set

6-1/4 inch grate: $\frac{9.4-8.4}{8.4}$ tons/hour = 11.9% increase

1.119 x 1200 = 1430 or 1450 tons/set

Welding initially takes 10 rods of Amsco Super 20. Daily touch up requires 5 additional rods each time. The hammers lasting 1200 tons were retouched 14 times. The cost of hammers with salvage value subtracted has previously been computed at $145.

A 50-lb. box of Amsco Super 20, 3/16-inch electrodes costs $1.80/lb. and contains 180 rods.

Cost per Rod: 50 lb. @ $1.80 = $90 or $.50/rod

The number of rods required for use with the 4-inch grate is

10 original + (14 touch-ups x 5) = 80 rods @ $.50 = $40.

More frequent touching up will be required with the larger grates because more tonnage is being milled. The increase in rods used for touch up is calculated as:

5-inch grate: 1.07 x 70 = 75 + original 10 = 85 @ $.50 = $42.50

6-1/4 inch grate: 1.12 x 70 = 80 + original 10 = 90 @ $.50 = $45

The annual cost of hammers includes the cost of hammers minus salvage plus welding rods.

The number of sets of hammers used annually is:

4-inch grate: $\frac{10{,}750 \text{ tons/yr.}}{1{,}200 \text{ tons/set}} = 9$ sets/year

5-inch grate: $\frac{11{,}520 \text{ tons/yr.}}{1{,}300 \text{ tons/set}} = 9$ sets/year

6-1/4 inch grate: $\frac{12{,}030 \text{ tons/yr.}}{1{,}450 \text{ tons/set}} = 9$ sets/year

The annual cost is:

		Grate Size	
	4-Inch	5-Inch	6-1/4 Inch
Cost of Hammers	$ 145/set	$ 145/set	$ 145/set
Cost of Welding Rods	40/set	42/set	45/set
	$ 185/set	$ 187/set	$ 190/set
Number of Sets	x 9	x 9	x 9
Annual Cost of Hammers And Welding Rods	$ 1,665	$ 1,683	$ 1,710
Annual Tonnage	$10,750	$11,520	$12,030
Cost Per Ton	$ 0.16	$ 0.15	$ 0.14

F - Analysis of Gondard Plant Shutdowns

The following table lists the days that the plant was shut down and the reasons for the shutdown and the probable solution for this type of shutdown. The plant was operating every day from September 18, 1967 through May 31, 1969, excepting the dates noted below. The conclusion to be drawn from the following table is that most all shutdowns of this pilot plant could be remedied in future plants through proper design and by scheduling maintenance not to interfere with daily production.

Date (Starting 9-18-67)	Reason	Solution or Possibility of Recurrence
9-22-67	Truck broke down and did not operate properly when repaired by the garage.	Truck breakdowns will occur periodically. A standby truck should be kept on site, or arrangements made to obtain a spare from the collection truck fleet.
10-18-67	Demonstration for Wisconsin League of Municipalities	Demonstrations would not need to take a full day, if the plant was not cleaned thoroughly.
1-2-68	Changed grates and installed hammers. The plant operator attended a meeting to reevaluate jobs at plant.	Grate and hammer work could be done on overtime.
1-9-68 1-10-68	A new discharge chute was constructed under the mill.	Proper initial construction.
3-1-68 thru 3-12-68	Head shaft on elevating conveyor broke. A stronger pulley was constructed and installed. The reject chute was also changed.	This problem has not recurred since a stronger head shaft pulley was installed.

Date	Reason	Solution or Possibility of Recurrence
3-19-68	Haul roads were being built.	Can be eliminated by providing drainage, and planning for wet weather operations.
4-24-68	Two men were sick. Cleaned plant, touched up surface hardening on hammers, and prepared to mill all of the next day's refuse.	The plant should operate with substitutes. However, the plant was purposely prepared for milling all the refuse collected the next day.
6-28-68	Changed grates for experimental purposes.	Grates would not be changed as frequently as was done for experimental reasons and could be done on overtime.
7-26-68	Made mill repairs, changed grates, filled in drainage trough and changed hammers.	Periodic repairs are necessary but should be done on overtime, or subcontracted.
8-2-68 8-5-68	The variable speed drive belt in the motor for the elevating conveyor broke.	The drive belts will wear with time and will have to be replaced periodically. However, this belt wore faster than expected.
End of Experimental Runs		
8-21-68 thru 8-29-68	Repair the mill and place vertical sides on part of the pan feeder.	Mill repairs are periodically required (see note for 7-26-68). Constructing the pan feeder with vertical sides would eliminate need for this modification.
9-13-68	Changed grates for experimental purposes.	See note for 6-28-68.

Date	Reason	Solution or Possibility of Recurrence
9-26-68 9-27-68	Repair the wear plates in the mill.	See note for 7-26-68.
10-23-68	The grates and wear plates in the mill were built up and hard surfaced.	See note for 7-26-68.
11-1-68 thru 11-7-68	Repair mill. A broken spacer shaft was replaced and new spacer rings were installed. Also, the wear plates were resurfaced and the reject chute repaired.	New shafts and spacers will occasionally be needed. Also, see note for 7-26-68.
11-18-68	Mass sick call because of city wage dispute.	
11-21-68	The rotor of the mill was rebalanced.	See note for 7-26-68.
1-13-69 thru 1-17-69	Cleats were placed on the transverse conveyor to aid the flow of refuse.	Proper initial construction. Maintenance could be scheduled during other major repairs.
1-22-69	A haulaway truck had to be taken to Milwaukee for repair of a broken part.	Have an unused truck from collection fleet ready for emergency use.
1-31-69	A new wear plate had to be placed in mill when attempts to patch old plate were unsuccessful.	Repair plates before they get completely worn.
3-28-69	Sympathy strike with city firemen.	

Date	Reason	Solution or Possibility of Recurrence
4-3-69 and 4-4-69	Reconstruct reject chute to telescope out of way to facilitate maintenance on the mill.	Proper initial design.
5-5-69	Removed excessively worn wear plates and made replacements. Also changed hammers.	More frequent attention and scheduling of work.
5-12-69 thru 5-15-69	Replacement of the return, guide track of the bin conveyor which wore and broke.	Heavier initial construction. More frequent inspection and lubrication. Scheduling of necessary repairs at same time as other major repairs.
5-29-69	Cleaned entire plant; hard-surfaced the hammers; and made mill repairs.	This should be scheduled over several working days.

G - Cost Comparison of Hammer Tipping Versus Non-Tipping

From observations and practical experience it is known that tipping of hammers reduces hammer wear and appears to save money, but no data have been recorded to support these observations. To get such data, two ten-day periods were set up to compare normal milling operations using the Tollemache Mill. The first period was completed using untipped hammers, the second using tipped hammers. Data were kept almost exclusively by plant personnel and consisted of the number of hammers used, welding rods used, and labor involved in changing and tipping hammers.

Cost Comparison

It was felt that for the purposes of this study the most meaningful comparisons could be obtained on a cost-per-ton basis. Costs considered will be for materials used and for labor expended during the two test periods. Other costs do enter into the comparison, such as depreciated value of welding equipment, electrical costs, etc., but these costs are nominal in comparison to labor and material costs. Table G-1 shows a comparison of material costs for Period I (no tipping) and Period II (tipping applied).

Table G-1

Cost of Materials Used

Period**	Hammers Used	Rods Used	Hammers	Welding Rods	Total Net Cost	Tons Milled	Cost Per Ton
I	80	0	$249	$ 0	$249	610	$0.408
II	34	53	102	27	129	644	0.200

**Period I - January 21 to February 3, 1971, no tipping
Period II -February 4 to February 17, 1971, hammers tipped

Table G-1 shows that cost of materials during Period I was almost twice that of Period II, indicating a significant gain by tipping hammers. Further comparison is made with respect to labor costs in Table G-2.

Table G-2

Cost of Labor Used

	Total Hours		Hours/Week				
	Operational	Man	Operational	Man	Total Cost	Tons Milled	Cost per Ton
Period I							
Hammer Changing	7.75	15.5	3.35	7.75	$108	610	$0.177
Period II							
Hammer Changing	4.5	9.0	2.25	4.50	63	644	$0.098
Hammer Tipping	4.7	4.7	2.35	2.35	33	644	0.051
Totals for Period II	9.2	13.7	4.60	6.85	$ 96	644	$0.149

Table G-3 presents a comparison of the total cost of the hammer maintenance programs for both Period I and Period II.

Table G-3

Total Cost of Hammer Maintenance Program

	Period I Nontipped Hammers		Period II Tipped Hammers	
	Cost	Cost/Ton	Cost	Cost/Ton
Hammers	$249	$0.408	$102	$0.159
Welding Rods	0	0	27	0.042
Labor (Hammer Changing)	108	0.177	63	0.098
Labor (Hammer Tipping)	0	0	33	0.051
TOTAL	$357	$0.585	$225	$0.350

A significant savings of over 23 cents per ton is indicated in Table G-3. At a rate of 50,000 tons of refuse milled per year, the city can save $11,500 by tipping the mill hammers.

There were some indications that the figure of 23 cents per ton may be conservative. For instance, when no tipping program was in force, plant personnel neglected to check regularly the inside of the mill. Consequently, hammers were not changed as often as they should have been, resulting in a larger particle size for the end product. Although particle size is not considered as a means of determining when to change hammers, a larger than desirable particle size does result from badly worn hammers.

H - Annual Tollemache Depreciation Date for Milling and Hauling Systems

(Applicable to Test Periods I and II Exclusively)

Depreciation or annual cost as presented in Table H-1, Annual Depreciation Data for Milling System, and Table H-2, Annual Depreciation for Stationary Compactor and Final Transportation System, is computed using the following equation*:

$$A.C. = (P-L)\ (CRF - i\% - n) + Li$$

where; $A.C.$ = Annual Cost

P = Initial Investment

L = Salvage Value

CRF = Capital Recovery Factor

$i\%$ = Interest Rate

n = Rated Full Life

The interest rate is a function of the expenditure involved. The city of Madison, Wisconsin will find the purchases of equipment for the plant by either long-term or short-term notes. The larger expenditures are usually paid by bonds and the smaller by notes. The interest rates in effect at the time the evaluations took place were 5.9% on bonds and 6.5% on notes. Tables H-1 and H-2 contain all pertinent data in respect to depreciation computations.

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*Grant, E. L., and W. G. Ireson, Principles of engineering economy. 4th ed. New York, the Roland Press Company, 1964. 574 p.

Table H-1

Annual Depreciation Data for Milling System

Item	Original Cost	Effective Life (Yrs)	Interest Rate	Salvage Value	Annual Cost
Building and Foundation	$133,118	20	5.9%	$4,000	$11,390
Tollemache Mill and Conveyors	87,600	15	5.9%	4,000	8,640
Scale	5,916	20	6.5%	1,000	600
Front-End Loader	15,400	12	6.5%	3,000	1,700
TOTAL					$22,390

The total annual cost of $22,970 can be proportioned to the 14 week and 8 week evaluation periods on a straight line basis. Depreciation for the 14 week evaluation is 14/52 ($22,390) = $6,034 and for the 8 week period 8/52 ($22,390) = $3,448.

Table H-2

Annual Depreciation Data for Stationary Compactor and Final Transportation System

Item	Original Cost	Effective Life (Yrs)	Interest Rate	Salvage Value	Annual Cost
Stationary Compactor and Hopper	$19,150	15	6.5%	$1,000	$2,000
Two Trailers	33,000	12	6.5%	1,500	3,960
One Tractor	13,625	15	6.5%	1,500	1,390
Building Addition	16,801	20	6.5%	1,000	1,500
TOTAL					$8,850

As with the milling system, the annual cost computed in Table H - 2 can be proportional to the 14 and 8 week evaluation periods. The results are a depreciation cost of $2,385 for 14 weeks and $1,360 for 8 weeks.

I - Supplemental Data - Tollemache Experimental Run

Period 1 (July 6, 1970 - October 9, 1970)

Table I-1

Summary of Experimental Run

Tollemache Mill, July 6, 1970 - October 9, 1970

PLANT PERFORMANCE		
Tons Milled	5,406.0	
Milling Time - Hours	365.8	
Down Time - Hours	9.5	
Total Time - Hours	375.3	
Production Rates - Tons per Hour	Operating	Overall
	14.53	14.18
REFUSE QUANTITIES		
Total Tons Received at Site	6,406	
Total Milled - Tons	5,318	
Total Unprocessed - Tons	1,088	
Percentage Milled	83%	
MAN-HOURS PER WEEK (AVERAGE)		
Regular[1]	126	
Overtime	12	
UTILITY AND EQUIPMENT USAGE		
220 Volt Service - Kilowatt Hours	13,760	
440 Volt Service - Total Kilowatt Hours	33,968	
440 Volt Service - Mill - Kilowatt Hours	2,670	
Water Cubic Feet		
Gas Cubic Feet	6,000	
Front-End Loader - Hours	85.6	
Tractor No. 586 - Miles	—	
Transfer Trailers - No. 760 - Hours	14.4	
- No. 761 - Hours	13.7	

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[1] Includes 6 hours per week supervision.

Table I-2

Table of Labor Rates

Effective July 6, 1970

Position	Basic Hourly Wage *	Average Annual Hourly Wage**
Plant Foreman	$5.26	$7.37
Mill Operator I	$4.72	$6.78
Public Works Maintenance Man I	$4.21	$6.24

*Does not include fringe benefits.
**Includes basic hourly wage, fringe benefits, overtime and substitute pay per employee as follows:

1) Social Security - 4.8% on first $7,800
2) Retirement - 11.04% on first $7,800
3) Health Insurance - $17.19 per month (family plan)
4) Life Insurance - ranges from $5.00 to $21.00 per year as age of employee increases
5) Vacation Substitute - $500/yr. to $800/yr. depending on lengtn of service
6) Sick Day Substitute - $480/yr.
7) Overtime - based on estimated hours of overtime allotted each employee per year:

200 hrs/yr - Foreman
225 hrs/yr - Mill Operator
300 hrs/yr - Maintenance Man I

The method used to compute the average annual wage is contained in Appendix K.

Table I-3

Power and Utility Rates

220 SERVICE		
Demand Charge	- First 10 kw or less per month	$ .75
	- Over 10 kw per month per kw	$1.70
Energy Charge	- First 500 kwh per month per kwh	$ .0233
	- Next 9,500 kwh per month per kwh	$ .0165
	- Next 10,000 kwh per month per kwh	$ .0140
440 SERVICE		
Demand Charge	- First 10 kw or less per month	$1.70
	- Next 90 kw per month per kw	$1.70
	- Over 100 kw per month per kw	$ .85
Energy Charge	- First 1200 kwh per month per kwh	$ .0233
	- Over 1200 kwh per month per kwh	$ .009

Table I-4

Equipment Maintenance Rates

Tractor	$0.15/mile
Transfer Trailers	$0.50/hour
Front-End Loader	$3.40/hour

J - Supplemental Data - Tollemache Experimental Run - Period 2

(February 4, 1971 to March 31, 1971)

Table J-1

Summary of Experimental Run

Tollemache Mill, February 4, 1971 to March 31, 1971

PLANT PERFORMANCE		
Tons Milled	2,624	
Milling Time - Hours	204.5	
Down Time - Hours	4.2	
Total Time - Hours	208.7	
Production Rates - Tons per Hour	Operational	Overall
	12.83	12.58
REFUSE QUANTITIES		
Total Tons Received at Site	2,640	
Total Milled - Tons	2,624	
Total Unprocessed - Tons	16	
Percentage Milled	99%	
MAN-HOURS PER WEEK (AVERAGE)		
Regular[1]	128	
Overtime	11.3	
UTILITY AND EQUIPMENT USAGE		
220-Volt Service - Kwh	12,710	
440-Volt Service - Overall - Kwh	29,280	
440-Volt Service - Mill - Kwh	23,136	
Water - Cubic Feet	2,850	
Gas - 100 Cubic Feet	4,640	
Front-End Loader - Hours	48.3	
Tractor No. 586 - Miles	178.3	
Transfer Trailer - No. 760 - Hours	4.8	
- No. 761 - Hours	6.9	

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[1] Includes 8 hours per week supervision

Table J-2

Table of Labor Rates

Effective January 1, 1971

Position	Basic Hourly Wage*	Average Annual Hourly Wage**
Plant Foreman	$5.66	$7.94
Mill Operator I	$4.72	$6.78
Public Works Maintenance Man I	$4.21	$6.24

*Does not include fringe benefits.
**Includes basic hourly wage, fringe benefits, overtime and substitute pay per employee as follows:

1) Social Security - 5.2% on first $7,800
2) Retirement - 4.5% on first $7,800, 7.0% on remaining.
3) Health Insurance - $27.40 per month (Family Plan).
4) Life Insurance - ranges from $12 to $37 per year as age of employee increases.
5) Vacation Substitute - $700 to $1200 per year depending on length of service
6) Sick Day Substitute - $480 per year.
7) Overtime - based on estimated hours of overtime allotted each employee per year:
   - 200 hrs./yr. - Foreman
   - 225 hrs./yr. - Mill Operator
   - 300 hrs./yr. - Maintenance Man I

The method used to compute annual wage is contained in Appendix K.

Table J-3

Power and Utility Rates

220 SERVICE

Demand Charge	- First 10 kw per month	$1.00
	- Next 490 kw per month per kw	$2.00
	- Next 500 kw per month per kw	$1.75
	- Next 1000 kw per month per kw	$1.10
	- Over 200 kw per month per kw	$0.80
Energy Charge	- First 500 kwh per month per kwh	$0.0260
	- Next 9500 kwh per month per kwh	$0.0183
	- Next 10,000 kwh per month per kwh	$0.0150
	- Next 30,000 kwh per month per kwh	$0.0120
	- Next 50,000 kwh per month per kwh	$0.0100
	- Over 100,000 kwh per month per kwh	$0.0095

440 SERVICE

Demand Charge	- First 10 kw or less per month	$2.00
	- Next 90 kw per kw per month	$2.00
	- Next 900 kw per kw per month	$1.00
	- Over 1000 kw per kw per month	$0.80
Energy Charge	- First 500 kwh per month per kwh	$0.0260
	- Next 1000 kwh per month per kwh	$0.0150
	- Next 8500 kwh per month per kwh	$0.0110
	- Next 90,000 kwh per month per kwh	$0.0100
	- Over 100,000 kwh per month per kwh	$0.0095

Table J-3 (cont.)

GAS SERVICE

Fixed Charge	$0.750
- First 2,000 cu. ft. per month per 100 cu. ft.	$0.135
- Next 3,000 cu. ft. per month per 100 cu. ft.	$0.126
- Next 195,000 cu. ft. per month per 100 cu. ft.	$0.0965
- Over 200,000 cu. ft. per month per 100 cu. ft.	$0.081

Table J-4

Equipment Maintenance Rates

Tractor No. 586	$0.20/mile
Front-End Loader	$4.25/hour
Transfer Trailers	$0.65/hour

K - Wage Rates Effective July 1, 1972

Table K-1

Average Annual Hourly Wage

	Fringes Included Per/Hr.	No Fringes Per/Hr.
Supervisor	$6.2539	$5.1745
Foreman, 1st Shift	8.0154	5.6375
Operator, 1st Shift	7.2083	4.9500
Maintenance Man, 1st Shift	6.1986	4.2229
Foreman, 2nd Shift	7.2280	5.1000
Operator, 2nd Shift	6.8932	4.8000
Maintenance Man, 2nd Shift	6.4478	4.3654
Plant Average (not including supervisor)	$6.9927	$4.8440

Table K-2

Average Annual Hourly Wage Rates

(Effective June 30, 1972)

REFUSE REDUCTION PLANT SUPERVISOR

Basic Wage Rate: $5.1745/hour
12 days paid vacation per year
12 days paid sick leave per year

Base Pay:	$5.1745/hour x 2,080 hours/year	$10,763
Overtime:	$7.7617/hour x 100 hours/year	776
Subtotal		$11,539
Social Security:	5.2% x $9,000	468
Retirement:	4.5% x $9,000	405
	7.0% x $2,539	178
Health Ins.:	0.667 x $48.66/mo. x 12 mo./yr.	389
Life Insurance:	$1.88/mo. x 12 mo./yr.	23
Subtotal		$ 1,463
TOTAL		$13,002

Average Hourly Wage $\frac{\$13,002}{2080 \text{ hrs/yr}}$ = $6.2539/hour

REFUSE REDUCTION PLANT FOREMAN - FIRST SHIFT

Basic Wage Rate: $5.6375/hour
22 days paid vacation per year
12 days paid sick leave per year

Base Pay:	$5.6375/hour x 2080 hours/year	$11,726
Overtime:	$8.4563/hour x 200 hours/year	1,691
Subtotal		$13,417
Social Security:	5.2% x $9,000	468
Retirement:	4.5% x $9,000	405
	7.0% x $4,417	309
Health Ins.:	0.667 x $48.66/mo x 12 mo./yr.	389
Life Insurance:	$3.68/mo. x 12 mo./yr.	44
Subtotal		$ 1,615
Vacation Substitute	22 days x 8 hr/day x $6.00/hr.	1,056
Sick Leave Substitute	12 days x 8 hrs./day x $6.00/hr.	576
TOTAL		$16,664

Average Hourly Wage $\frac{\$16,664}{2080 \text{ hrs./yr.}}$ = $8.0154/hour

REFUSE REDUCTION PLANT OPERATOR - FIRST SHIFT

Basic Wage Rate: $4.9500/hour
19.5 days paid vacation per year
12 days paid sick leave per year

Base Pay:	$4.9500/hour x 2080 hours/year	$10,296
Overtime:	$7.4250/hour x 225 hours/year	1,671
Subtotal		$11,967
Social Security:	5.2% x $9,000	468
Retirement:	4.5% x $9,000	405
	7.0% x $2,967	208
Health Ins.:	0.667 x $48.66/mo. x 12 mo./yr.	389
Life Insurance:	$3.10/mo. x 12 mo./yr.	37
Subtotal		$ 1,507
Vacation Substitute	19.5 days x 8 hrs./day x $6.00/hr.	936
Sick Leave Substitute	12 days x 8 hrs./day x $6.00/hr.	576
TOTAL		$14,986

Average Hourly Wage $\frac{\$14,986}{2080\ \text{hrs./yr.}} = \$7.2083/\text{hour}$

REFUSE REDUCTION PLANT MAINTENANCE MAN - FIRST SHIFT

Basic Wage Rate: $4.2229/ hour
12 days paid vacation per year
12 days paid sick leave per year

Base Pay:	$4.2229/hour x 2080 hours/year	$ 8,784
Overtime:	$6.3343/hour x 250 hours/year	1,584
Subtotal		$10,368
Social Security:	5.2% x $9,000	468
Retirement:	4.5% x $9,000	405
	7.0% x $1,368	96
Health Ins.:	0.667 x $48.66/mo. x 12 mo./yr.	389
Life Insurance:	$0.75/mo. x 12 mo./yr.	9
Subtotal		$ 1,367
Vacation Substitute	12 days x 8 hrs./day x $6.00/hr.	576
Sick Leave Substitute	12 days x 8 hrs./day x $6.00/hr.	576
TOTAL		$12,887

Average Hourly Wage $\frac{\$12,887}{2080\ \text{hrs./yr.}} = \$6.1986/\text{hr.}$

REFUSE REDUCTION PLANT FOREMAN - SECOND SHIFT

Basic Wage Rate: $5.1000/hr.
17 days paid vacation per year
12 days paid sick leave per year

Base Pay:	$5.1000/hr. x 2080 hours/year	$10,608
Overtime:	$7.6500/hr. x 200 hours/year	1,530
Subtotal		$12,138
Social Security:	5.2% x $9,000	468
Retirement:	4.5% x $9,000	405
	7.0% x $3,138	220
Health Ins.:	0.667 x $48.66/mo. x 12 mo./yr.	389
Life Insurance:	$1.22/mo. x 12 mo./yr.	15
Subtotal		$ 1,497
Vacation Substitute	17 days x 8 hrs./day x $6.00/hr.	816
Sick Leave Substitute	12 day x 8 hrs./day x $6.00/hr.	576
TOTAL		$15,027

Average Hourly Wage $\frac{\$15,027}{2080 \text{ hrs./yr.}} = \$7.2280/\text{hr.}$

REFUSE REDUCTION PLANT OPERATOR - SECOND SHIFT

Basic Wage Rate: $4.8000/hour
14.5 days paid vacation per year
12 days paid sick leave per year

Base Pay:	$4.8000/hour x 2080 hours/year	$ 9,984
Overtime:	$7.2000/hour x 225 hours/year	1,620
Subtotal		$11,604
Social Security:	5.2% x $9,000	468
Retirement:	4.5% x $9,000	405
	7.0% x $2,604	182
Health Ins.:	0.667 x $48.66/mo. x 12 mo./yr.	389
Life Insurance:	$0.94 mo. x 12 mo/yr.	11
Subtotal		$ 1,455
Vacation Substitute	14.5 days x 8 hrs/day x $6.00/hr.	696
Sick Leave Substitute	12 days x 8 hrs/day x $6.00/hr.	576
TOTAL		$14,331

Average Hourly Wage $\frac{\$14,331}{2080 \text{ hrs./yr.}} = \$6.8932/\text{hr.}$

REFUSE REDUCTION PLANT MAINTENANCE MAN - SECOND SHIFT

Basic Wage Rate: $4.3654/hour
14.5 days paid vacation per year
12 days paid sick leave per year

Base Pay:	$4.3654/hour x 2080 hours/year	$ 9,080
Overtime:	$6,5481/hour x 250 hours/year	1,637
Subtotal		$10,717
Social Security:	5.2% x $9,000	468
Retirement:	4.5% x $9,000	405
	7.0% x $1,717	120
Health Ins.:	0.667 x $48.66/mo. x 12 mo./yr.	389
Life Insurance:	$2.82/mo. x 12 mo./yr.	34
Subtotal		$ 1,416
Vacation Substitute	14.5 days x 8 hrs/day x $6.00/hr.	696
Sick Leave Substitute	12 days x 8 hrs/day x $6.00/hr.	576
TOTAL		$13,405

Average Hourly Wage $\frac{\$13,405}{2080 \text{ hrs./yr.}}$ = $6.4478/hour

L - Annual Two-Mill, Two-Shift Depreciation Data For Milling and Hauling Systems

(January 1 to July 1, 1972)

Depreciation or annual cost for both the milling and hauling systems is presented in Tables L-1 and L-2. Calculations are based on the annual cost equation used in Appendix H. The interest rates used for these calculations are those that were in effect on August 17, 1972. These rates are 4.0 for long term bonds and 3.9 on short term notes.

Table L-1

Annual Depreciation Data For Milling System

Item	Original Cost	Effective Life (Yrs.)	Interest Rate (%)	Salvage Value	Annual Cost
Building and Foundation	$133,118	20	4.0	$ 4,000	$ 9,660
Building Expansion	98,000	20	4.0	3,500	7,090
Gondard mill and Conveyors	126,705	15	4.0	4,000	11,200
Tollemache Mill and Conveyors	87,600	15	4.0	4,000	7,680
Scale	5,916	20	3.9	1,000	400
Front End Loader	32,115	12	3.9	10,000	2,730
Floor Sweeper	3,462	10	3.9	500	380
TOTAL					$39,140

Total annual costs for the milling system are $39,140. Proportioning this to the 6-month operation yields a depreciation cost of $19,570.

Table L-2

Annual Depreciation Data For Stationary Compactor And Final Transportation System

Item	Original Cost	Effective Life (Yrs.)	Interest Rate (%)	Salvage Value	Annual Cost
Stationary Compactor and Hopper	$19,150	15	3.9	$1,000	$1,640
Two Trailers	33,000	12	3.9	1,500	3,400
Two Tractors	30,300	15	3.9	3,000	2,530
Building Addition	16,800	20	3.9	1,000	1,190
TOTAL					$8,760

Total annual cost for the hauling is $8,760. Again, proportioning this to 6 months' operation gives a value of $4,380.

M - Supplemental Data--Two-Mill, Two-Shift Operation (January 1 to July 1, 1972)

TABLE M-1

Power and Utility Rates

440 SERVICE - STANDARD POWER

Demand Charge -	First 10 kw or less per month	$2.00
	Next 90 kw per kw per month	$2.00
	Next 900 kw per kw per month	$1.00
	Over 1,000 kw per kw per month	$0.80
Energy Charge -	First 500 kwh per month per kwh	2.60¢
	Next 1,000 kwh per month per kwh	1.50¢
	Next 8,500 kwh per month per kwh	1.10¢
	Next 90,000 kwh per month per kwh	1.00¢
	Next 100,000 kwh per month per kwh	0.95¢

220 SERVICE - COMMERCIAL LIGHTING AND POWER

Demand Charge -	First 10 kw or less per month	$1.00
	Next 490 kw per kw per month	$2.00
	Next 500 kw per kw per month	$1.75
	Next 1,000 kw per kw per month	$1.10
	Over 2,000 kw per kw per month	$0.80
Energy Charge -	First 500 kwh per month per kwh	2.60¢
	Next 9,500 kwh per month per kwh	1.83¢
	Next 10,000 kwh per month per kwh	.50¢
	Next 30,000 kwh per month per kwh	1.20¢
	Next 50,000 kwh per month per kwh	1.00¢
	Over 100,000 kwh per month per kwh	0.95¢

GAS SERVICE

Fixed charge	75.0¢
First 2,000 cu.ft. per month per 100 cu.ft.	13.5¢
Next 3,000 cu.ft. per month per 100 cu.ft.	12.6¢
Next 195,000 cu.ft. per month per 100 cu.ft.	9.65¢
Over 200,000 cu.ft. per month per 100 cu.ft.	8.1¢

TABLE M-2

Equipment Maintenance Rates

Front End Loader	$4.25/hr.
Tractors No. 586 and No. 587	$0.20/mi.
Transfer Trailers	$0.25/mi.

N - Cost Projections For New Milling Plants and Landfills

This segment of the report includes detailed data in respect to operating requirements and cost projections for a combination of one through four mills operated either one or two operating shifts with one maintenance shift. The estimates given in this portion of the report are based on data collected utilizing the Tollemache vertical shaft hammermill in Madison, Wisconsin. It is important to realize that the cost projections have been developed on the basis of costs at Madison. The wage rates, power and utility rates, depreciation, etc. are all based on 1972 Madison cost data. To arrive at projected costs for similar operations an economic study following the lines of that presented below may be made using the appropriate base rates as applied to the area being studied.

Basic Design Criteria

The following design criteria were used in plant design and eventual cost projections:

(1) Each mill will operate an average of 7 hours per shift at a rate of 14 tons per hour.

(2) The plant will operate 245 days or 49 weeks per year. Three weeks are allowed for repairs and breakdowns.

(3) The milling production day (one or two milling shifts) will be followed by an eight-hour maintenance shift.

(4) Each plant will have as many feed conveyors as mills. One and two mill plants will have one discharge conveyor and one stationary compactor.

(5) Plants containing 3 or 4 mills will have two discharge conveyors and two stationary compactors.

(6) Cost projections are primarily based on pilot plant and two shift studies conducted with the equipment mentioned in the text.

(7) All pertinent data as to wage rates, utility rates, depreciation, etc. are based on the evaluation data from Madison.

Annual Tonnage

Each Tollemache mill operating one shift will have a daily capacity of 14 tons/hour x 7 hours/day, or approximately 100 tons per day. The corresponding annual tonnage for one mill shift will be 100 tons/day x

245 days/year = 24,500 tons per year. Daily and annual tonnages for combinations of mills and shifts are listed in Table N-1.

TABLE N-1

Daily and Annual Tonnage Processed for Combinations of Mills and Shifts

	Number of Mills			
	1	2	3	4
One Shift				
Daily Tonnage	100	200	300	400
Annual Tonnage	24,500	49,000	73,500	98,000
Two Shifts				
Daily Tonnage	200	400	600	800
Annual Tonnage	49,000	98,000	147,000	196,000

Size of Plant

Experience has shown refuse quantities to vary throughout the year. Peak tonnage rates are about 1.5 times the average daily tonnage. Good plant design involves increasing available storage to allow for mill breakdowns, etc. A factor about 1.5 times the average daily tonnage through the plant is used to determine storage space. The maximum storage requirement then becomes 150 percent of the average daily tonnage processed on a one shift basis and is reduced to 125 percent of the daily tonnage processed on a two shift basis. The reduction in excess capacity is due to an increase in scale.

The maximum storage which must be provided is listed in Table N-2 The values in Table N-2 were determined by multiplying the daily tonnage in Table N-1 by 150 percent for plants operating one shift, and by 125 percent for plants operating two shifts.

TABLE N-2

Maximum Storage Requirements for Combinations of Mills and Shifts - Tons

	Number of Mills			
	1	2	3	4
One Shift	150	300	450	600
Two Shifts	250	500	750	1,000

Assuming a density of 400 pounds per cubic yard on the dumping floor, and an average stacked storage height of 8 feet, 0.53 ton can be stored per square yard of floor space, or 0.059 tons per square foot of floor space. The square footage of floor storage is computed by dividing the tonnages in Table N-2 by 0.059 ton per square foot.

TABLE N-3

Square Footage of Floor Storage Space Required For Combinations of Mills and Shifts

	Number of Mills			
	1	2	3	4
One Shift	2,500	5,000	7,500	10,000
Two Shifts	4,300	8,500	12,700	17,000

The total plant size including refuse storage space on the floor, conveyors and mills, and office is tabulated below. (A plant with three or four mills will be considered to be equipped with two discharge conveyors and two stationary compactors.)

TABLE N-4

Total Plant Size - Square Feet

	Number of Mills			
	1	2	3	4
One Shift				
Office & Workshop	1,000	1,000	1,500	1,500
Employee Facilities	300	300	500	500
Conveyor(s), Mill(s) and Compactor(s)	3,500	5,000	9,000	10,500
Floor Storage-Refuse	2,500	5,000	7,500	10,000
TOTAL	7,300	11,300	18,500	22,500
Two Shifts				
Office & Workshop	1,000	1,000	1,500	1,500
Employee Facilities	500	500	700	700
Conveyor(s), Mill(s) and Compactor(s)	3,500	5,000	9,000	10,500
Floor Storage-Refuse	4,300	8,500	12,700	17,000
TOTAL	8,800	15,000	23,900	29,700

The cost of foundations and building is computed by multiplying the total space requirements in Table N-4 by $20 per square foot. The entrance road and site grading is computed on the basis of 20 percent of the foundations and building construction costs.

TABLE N-5

Cost of Foundations, Buildings, Entrance, Roads, and Grounds
For Combinations of Mills and Shifts

		1	2	3	4
One Shift	- Foundations and Buildings	$146,000	$226,000	$370,000	$450,000
	- Entrance Roads and Grounds	29,200	45,200	74,200	90,000
	TOTAL	$175,200	$271,200	$444,200	$540,000
Two Shift	- Foundations and Buildings	$176,000	$300,000	$478,000	$594,000
	- Entrance, Roads and Grounds	35,200	60,000	95,600	11,900
	TOTAL	$211,200	$360,000	$573,600	$605,900

Labor Requirements and Costs

The number of men needed to man the combination of mills and shifts under consideration are shown in Table N-6 as are the annual costs of labor. Past experience at Madison has shown the need for proper supervision at all levels of plant operation; thus, one supervisor is required for each case shown. Also included are two maintenance men for one and two mill installations and three maintenance men for three and four mill installations. These men will work an 8-hour maintenance shift following each day's milling operation, whether one or two milling shifts are used.

Mill Maintenance - Annual Cost

(1) Hammers - 1100 tons/set at $106 per set

(2) Shafts - 500 tons/shaft at $12.00/shaft

(3) Wear Plates - 20,000 tons/set at $1600 per set

(4) General Maintenance:

Mill - replace bearings and rotor once every three years for one shift operation, $2,500 for each mill operating one shift, and 80 percent additional for second shift.

Conveyors - $600 for the feed conveyor, and $200 for each discharge conveyor for one mill operating one shift. The cost for the second shift will be an additional 80 percent.

(5) Welding Rods - 34 rods/set at $.50/rod; or $17.00 per set of hammers. 50 lbs./liner set at $1.60/lb.; or $80.00 per set of liners.

(6) Plant Supplies - $1,200 per one mill shift; $500 additional for each mill; 50 percent additional for second shift.

TABLE N-6

Annual Labor Requirements and Costs

	Hourly Wage*	Annual Wage	Number of Mills 1	2	3	4
One Shift						
Supervisor	$6.26**	$13,000	1	1	1	1
Reduction Plant Foreman-Operator	$8.02	$16,660	1	1	1	2
Reduction Plant Operator	$7.21	$14,990	1	2	2	3
Public Works Maintenance Man	$6.20	$12,890	2	2	3	3
Scale Man	$4.73	$ 9,840	-	-	1	1
Total			$ 70,430	$ 85,420	$108,150	$139,800
Two Shifts						
Supervisor	$6.26	$13,000	1	1	1	1
Reduction Plant Foreman	$8.02	$16,660	2	2	2	4
Reduction Plant Operator	$7.21	$14,990	2	3	4	4
Public Works Maintenance Man	$6.20	$12,890	2	2	3	3
Scale Man	$4.73	$ 9,840	-	1	2	2
Total			$102,080	$126,910	$164,630	$197,950

*Including 30 percent fringe benefits and estimated overtime.

**Other employees salary higher due to longevity pay program in City of Madison.

TABLE N-7

Annual Mill Maintenance Costs

	Number of Mills			
	1	2	3	4
One Shift				
(1) Hammers	$ 2,330	$ 4,660	$ 6,990	$ 9,320
(2) Shafts	580	1,160	1,740	2,320
(3) Wear Plates	1,600	3,860	5,760	7,680
(4) General Maintenance				
Mill(s)	2,500	5,000	7,500	10,000
Conveyor(s)	800	1,600	2,800	4,000
(5) Welding Rods	370	740	1,110	1,480
(6) Plant Supplies	1,200	1,700	2,200	2,700
Total	$ 8,580	$18,720	$28,100	$37,500
Two Shifts				
(1) Hammers	$ 4,660	$ 9,320	$13,980	$18,640
(2) Shafts	1,160	2,320	5,480	4,640
(3) Liners	3,868	7,680	11,520	15,360
(4) General Maintenance				
Mill(s)	4,500	9,000	13,500	18,000
Conveyor(s)	1,440	2,800	5,040	7,200
(5) Welding Rods	740	1,480	2,220	2,960
(6) Plant Supplies	1,800	2,550	3,300	4,050
Total	$18,160	$35,150	$53,040	$70,850

Power for Mills, Conveyors, and Stationary Compactor

(1) The maximum demand for each mill and conveyor system is 160 kw.

(2) The maximum demand for the compactor is 20 kw.

(3) The power consumption for each mill and conveyor system averages 8.8 KWH/ton.

(4) The power consumption for each compactor is 16 KWH/hour.

The monthly demand charge for one mill and conveyor system is:

> $2.00 for the first 10 kw, $2.00 per kw for each of the next 90 kw, and $1.00 per kw up to the 160 kw required for a total of $242

The monthly demand charge for each additional mill and conveyor system is:

> $1.00 x 160 kw = $160

The monthly demand charge for each compactor is:

> $1.00/kw x 20 kw = $20

The power consumption for one mill and conveyor system operating one shift is 8.8 KWH/ton x 14 tons/hour = 123.2 KWH/hr. The monthly consumption then is 123.2 KWH/hour x 7 hours/day x 5 days/week x 4.0 weeks/month = 17,250 KWH/month. The monthly consumption cost for one mill operating one shift is: 0.026 x 500 KWH + $0.015 x 1000 KWH + $0.011 x 8500 KWH + $0.010 x 7,250 = $194. The monthly consumption for all additional mill-shifts is $0.010 x 17,250 KWH = $172. The monthly power consumption for each compactor working each shift is 16 KWH/hr x 7 hrs./shift day x 5 days/week x 4.0 weeks/month = 2,240 KWH/month. The corresponding monthly consumption cost for each compactor shift is $0.080 x 2,240 KWH = $22. The above listed power consumption costs are summarized as follows:

> The monthly power consumption cost for the first mill-shift is $194.
>
> The monthly power consumption for all additional mill-shifts is $172.
>
> The monthly power consumption cost for all compactor-shifts is $22.

TABLE N-8

Annual Power Costs for Mill(s) Conveyor(s), and Compactors

		Number of Mills			
		1	2	3	4
One Shift					
Demand					
First Mill	$242	$ 242	$ 242	$ 242	$ 242
Each Addnl. Mill	160	-	160	320	480
Each Compactor	20	20	20	40	40
Power Consumption					
First Mill-Shift	194	194	194	194	194
Each Addnl. Mill-Shift	172	-	172	344	516
Each Compactor-Shift	22	22	22	44	44
Total Monthly Charge		$ 478	$ 810	$ 1,184	$ 1,516
Annual Charge		$5,736	$9,720	$14,208	$18,192
Two Shifts					
Demand	$242	$ 242	$ 242	$ 242	$ 242
Each Addnl. Mill	160	-	160	320	480
Each Compactor	20	20	20	40	40
Power Consumption					
First Mill-Shift	194	194	194	194	194
Each Addnl. Mill-Shift	172	172	516	860	1,204
Each Compactor-Shift	22	44	44	88	88
Total Monthly Charge		$ 672	$ 1,176	$ 1,744	$ 2,248
Annual Charge		$8,064	$14,112	$20,928	$26,976

Lighting

The consumption is to be proportioned on the basis of:

(1) The actual consumption in the reduction plant for one shift from July 1970 through December 1970, and for two shifts from January through June of 1972.

(2) The relative sizes of the buildings.

The original building used for a one-shift operation was 60 ft. x 100 ft. = 6,000 sq. ft. The expanded building used for the two-shift operation is approximately 13,000 sq. ft. The ratio of floor space for the projected plants, as listed in Table N-9 to 6,000 sq. ft. or 13,000 sq. ft. where applicable, is the relative size factor. The relative sizes are:

TABLE N-9

Relative Sizes of Buildings

	Number of Mills			
	1	2	3	4
One Shift	$\frac{7,300}{6,000} = 1.22$	$\frac{11,300}{6,000} = 1.88$	$\frac{18,500}{6,000} = 3.08$	$\frac{22,500}{6,000} = 3.75$
Two Shifts	$\frac{8,800}{13,000} = .68$	$\frac{15,000}{13,000} = 1.15$	$\frac{23,900}{13,000} = 1.84$	$\frac{29,700}{13,000} = 2.28$

Table N-10 shows the actual consumption for the existing plant per month studied, and the proportional usage based on relative building sizes, for one shift. Table N-11 contains the same information as related to a two-shift operation.

TABLE N-10

Actual and Proportioned Power Consumption (KWH) For Lighting-One Shift

		Number of Mills			
Month	Actual KWH Consumption	1	2	3	4
July 1970	4,414	5,385	8,298	13,595	16,552
August 1970	4,104	5,007	7,715	12,640	15,390
September 1970	4,018	4,902	7,554	12,375	15,068
October 1970	5,860	7,149	11,017	18,048	21,975
November 1970*	5,900	7,198	9,109	18,172	22,125
December 1970*	5,400	6,588	10,152	16,632	20,250
Average		6,038	8,974	15,243	18,560

*Figures adjusted - due to construction

TABLE N-11

Actual and Proportional Power Consumption (KWH) For Lighting-Two Shifts

Month	Actual KWH Consumption	Number of Mills 1	2	3	4
January 1972	18,788	12,775	21,606	34,570	42,836
February 1972	17,088	11,620	19,651	31,442	38,960
March 1972	19,286	13,114	22,179	35,486	43,972
April 1972	14,734	10,019	16,944	27,110	33,593
May 1972	12,772	8,650	14,687	23,500	29,006
June 1972	13,294	9,040	15,288	24,460	30,310
Average		10,868	18,393	29,590	36,446

Based on the data given in Tables N-10 and N-11 a fairly good monthly average of lighting power consumption for a one and two-shift operation can be obtained. Table N-12 contains this average in relation to number of mills.

TABLE N-12

Average Monthly Power Consumption (KWH) For Lighting One and Two Shifts

	Number of Mills 1	2	3	4
One Shift	6,038	8,974	15,243	18,560
Two Shift	10,868	18,393	29,590	36,446

The demand charge would also be proportional to the size of the building, but would be nearly constant throughout the year because the charge is based on the high during the preceding 12 months. The maximum demand for the original one-shift plant was 20 kw and for the two-shift plant 40 kw. The maximum demand to be expected in any of the projected plants is calculated by multiplying 20 kw or 40 kw whichever is applicable by the relative building sizes as listed in Table N-9. The maximum demand is tabulated below.

TABLE N-13

Maximum Demand For Lighting - kw

	Number of Mills 1	2	3	4
One Shift	24	38	62	75
Two Shifts	27	46	74	91

The annual cost of lighting can be computed using the monthly average consumption (KWH) and maximum demand as shown in Tables N-12 and N-13 and the current utility rates. Table N-14 contains the summary of lighting costs.

TABLE N-14

Annual Cost of Lighting for Combinations Of Mills and Shifts

	Number of Mills 1	2	3	4
One Shift				
Demand	$ 120	$ 696	$1,272	$1,584
Consumption	936	1,320	2,148	2,592
Total	$1,056	$2,016	$3,420	$4,176
Two Shifts				
Demand	$ 432	$ 888	$1,560	$1,968
Consumption	1,572	2,568	4,044	4,944
Total	$2,004	$3,456	$5,604	$6,912

Gas Heat

The gas costs are computed in a similar manner as for lighting costs because consumption is dependent on building size. The actual consumption is to be proportioned on the basis of:

(1) the actual consumption in the reduction plant for one shift from July 1970 through December 1970, and for two shifts from January through June of 1972, and

(2) the relative sizes of buildings.

The relative building sizes have been previously computed and are shown in Table N-4. The actual gas consumption for the existing plant, and the proportioned usage based on relative building size are shown in the following two tables.

TABLE N-15

Actual and Proportioned Gas Consumption (Heat) - One Shift

Month	Actual Consumption (Cu.ft.x100)	Number of Mills 1	2	3	4
July 1970	0	0	0	0	0
August 1970	0	0	0	0	0
September 1970	30	37	56	92	112
October 1970	780	952	1,466	2,402	2,925
November 1970	3,420	4,173	6,430	10,533	12,825
December 1970	3,600	4,392	6,768	11,088	13,500
Average		1,590	2,450	4,020	4,890

The consumption for two shifts is listed in the following table. The proportioned consumption was obtained by multiplying the relative building size by actual consumption used in the expanded plant under two-shift operation.

TABLE N-16

Actual and Proportioned Gas Consumption (Heat) - Two Shifts

Month	Actual Consumption (Cu.ft.x100)	Number of Mills 1	2	3	4
January 1972	8,679	5,900	9,980	15,970	19,790
February 1972	8,297	5,640	9,540	15,270	18,920
March 1972	5,124	3,480	5,890	9,430	11,680
April 1972	1,983	1,350	2,280	3,650	4,520
May 1972	618	420	710	1,140	1,410
June 1972	540	370	620	990	1,230
Average		2,860	4,840	7,740	9,590

Since only 6 months of good gas consumption data for a one and two shift operation at Madison is available, only a rough estimate of gas costs can be calculated. This estimate is computed by doubling the total cost figure obtained from the proportioned consumption as presented in Tables N-15 and N-16. The estimate is valid because each six-month's term studied contains equal periods of warm and cold weather in relation to that period not studied. Table N-17 contains the projected yearly costs for gas as heat, based on natural gas rates in effect at the time of evaluation.

TABLE N-17

Annual Cost of Gas (Heat)
One and Two Shifts

	Number of Mills			
	1	2	3	4
One Shift	$1,746	$2,580	$4,104	$4,950
Two Shifts	$2,976	$4,902	$7,722	$9,516

Water and Sewer

The usage is proportional to the tonnage milled, and has been found to cost $0.002 per ton. Rather than going through the tedious procedure used for estimating lighting and gas costs, the water and sewer costs are estimated by multiplying the annual tonnage by $0.002 per ton. This method is felt to be valid because the cost per ton was nearly constant throughout the periods tested, and because the volume consumed is low enough that the same utility rate applies.

TABLE N-18

Annual Water Costs for Combinations
Of Mills and Shifts
(Based on Cost of $0.002 Per Ton)

	Number of Mills			
	1	2	3	4
One Shift	$49	$ 98	$147	$196
Two Shifts	$98	$196	$294	$392

Tractor and Transfer Trailer Requirements

The number of trailers and tractors required is computed below. Based on actual data a 70-yard trailer loaded with 15 tons of milled refuse would have a density of 430 lbs. per cubic yard. Each trailer is limited to 15 tons because of State highway regulations. Past experience has shown that switching and unloading of each trailer averages 30 minutes when the plant is located on the fill site. At a mill production of 14 tons per hour one mill will fill one trailer in 64 minutes. Two mills operating at 14 tons per hour each will fill one trailer in 32 minutes. Thus a one mill plant will need a minimum of two trailers. A two mill plant could also function with only two trailers; but would be advised to have three to minimize production down time because of trailer breakdowns or delays in the switching-unloading process. Both a one mill and two mill plant would require only one tractor to pull the trailers. The above data would be applicable to a one shift or two shift operation.

As mentioned previously any three or four mill plant should contain two stationary compactors. Taking this and the above data into consideration, a three mill plant would require four trailers and a four mill plant five trailers. Each three and four mill plant should be equipped with a minimum of two tractors. Table N-19 summarizes the above data.

TABLE N-19

Tractor and Trailer Requirements

	Number of Mills			
	1	2	3	4
One Shift				
Tractors	1	1	2	3
Trailers	2	3	4	5
Two Shift				
Tractors	1	1	2	3
Trailers	2	3	4	5

Annual Tractor and Transfer Trailer Operation and Maintenance Costs

Maintenance on the tractors and trailers is charged on a mileage basis; \$0.20/mi. for tractors and \$0.25/mi. for trailers. To compute maintenance costs it is first necessary to determine the number of loads taken to the fill site; based on the information given above.

TABLE N-20

Number of Loads Per Day

	Number of Mills			
	1	2	3	4
One Shift	7	14	21	28
Two Shifts	14	28	42	56

The annual operating cost for the tractors can be computed as follows: multiply the number of daily trips by round trip distance traveled, 0.5 mile in Madison, x \$0.20/mi. x 245 operating days/year. The computation for the trailers is the same except \$0.25/mi. is used instead of \$0.20/mi. The appropriate annual cost for tractor and trailer maintenance is shown in Table N-21.

TABLE N-21

Annual Operation and Maintenance Cost For Tractor and Transfer Trailer Operation Per Unit

	Number of Mills			
	1	2	3	4
One Shift				
Tractors	$172	$ 344	$ 516	$ 688
Trailers	215	430	645	860
Total	$387	$ 774	$1,161	$1,548
Two Shifts				
Tractors	$344	$ 688	$1,032	$1,376
Trailers	430	860	1,290	1,720
Total	$774	$1,548	$2,322	$3,096

Annual Stationary Compactor Maintenance Costs

Past studies conducted at the Madison plant have revealed that on the average, stationary compactor maintenance has cost approximately $0.02/ton, based on a one shift operation. It would be reasonable to assume that a 50 percent increase in costs would be experienced when the machinery is operated on a two shift basis. Using these figures as a guide the annual operating costs for the combination of shifts and mills being studied is shown in Table N-22. It should be reemphasized that all three and four mill plants are designed for two compactors.

TABLE N-22

Annual Stationary Compactor Maintenance Costs

	Number of Mills			
	1	2	3	4
One Shift				
First Compactor	$ 480	$ 960	$ 960	$ 960
Second Compactor	-	-	480	960
Total	$ 480	$ 960	$1,440	$1,920
Second Shift				
First Compactor	$1,440	$2,880	$2,880	$2,880
Second Compactor	-	-	1,440	2,880
Total	$1,440	$2,880	$4,320	$5,760

Annual Front End Loader Operation and Maintenance

For one and two mill operations a small end loader would be sufficient to handle all tonnage processed. For a three and four mill plant, a medium range end loader would be required. The operation and maintenance of both pieces of equipment is assumed to cost $4.25/hr. The end loader will operate 5 hours and 10 hours per day for a one mill, one shift and one mill, two shift operation, respectively. The same piece of machinery will operate 6 hours and 12 hours per day for a two mill, one shift and two mill, two shift operation, respectively. The end loader will operate 7 and 14 hours for a three mill, one and two shift operation, and 7 and 14 hours for a four mill, one and two shift operation, respectively.

TABLE N-23

Annual Operation and Maintenance Costs
For Front End Loader

	Number of Mills			
	1	2	3	4
One Shift	$ 5,205	$ 6,246	$ 7,287	$ 7,287
Two Shifts	$10,410	$12,492	$14,575	$14,575

Amortization*

Amortization data and annual costs are listed below for all depreciable items.

Building

Amortize over 20 years at 4.0 percent interest, salvage estimated at 3.0 percent of original cost as contained in Table N-5.

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*Amortization or annual cost is calculated on the basis of the following equation: †

$$A.C. = (P-L)(CRF) - Li$$

where

A.C. = annual cost
P = initial investment
L = salvage value
CRF = capital recovery factor
i% = interest rate
N - rated full life

The interest rate, i%, used in the computations, is a function of the expenditure involved; i.e., short term notes or long term bonds. The City of Madison usually funds large expenditures by long term bonds. The interest rates in effect at the time of writing are 4.0 percent on long term bonds.

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†Grant, E. L., and W. G. Ireson. Principles of engineering economy. 4th Ed. New York, The Roland Press Company, 1964. 574 p.

TABLE N-24

Annual Cost of Foundation and Building

	Number of Mills 1	2	3	4
One Shift	$12,720	$19,690	$32,250	$39,200
Two Shifts	$15,330	$26,130	$41,640	$43,980

TABLE N-25

Amortization* Data and Annual Costs

Cost Item	Original Cost	Depreciation Rate-Yrs.	Int. Rate, %	Salvage Value	Annual Cost
Scale	$15,000	20	4.0	$ 1,000	$ 1,076
Front Endloader					
Michigan	$32,000	12	4.0	$ 5,000	$ 3,089
Case	$22,000	12	4.0	$ 3,000	$ 2,153
Grinder and Conveyor (ea)	$140,000	15	4.0	$ 4,000	$12,400
Stationary Compactor (ea)	$ 22,000	15	4.0	$ 1,000	$ 1,930
Trailers (ea)	$ 19,000	12	4.0	$ 750	$ 1,982
Tractor (ea)	$ 15,000	15	4.0	$ 1,500	$ 1,275

Annual Projected Operating and Amortization Costs For Combinations of Mills and Shifts

Tables N-26 and N-27 summarize all costs of operating the various sized plants and the amortization rates of each.

*NOTE: This is not a surplus fund for replacement of equipment, but reflects municipal approaches for amortization.

TABLE N-26

Annual Cost for One Through Four Mills - One Shift

	Number of Mills			
	1	2	3	4
Labor	$ 70,430	$ 85,420	$108,150	$139,800
Mill Maintenance	8,580	18,720	28,100	37,500
Power - Mills, Conveyors, and Compactors	5,740	9,720	14,210	18,190
Lighting	1,060	2,020	3,420	4,180
Gas (Heat)	1,750	2,580	4,100	4,950
Water	50	100	150	200
Tractor and Trailer Operations and Maintenance	390	770	1,160	1,550
Front End Loader Operation and Maintenance	5,210	6,250	7,290	7,290
Compactor Maintenance	480	960	1,440	1,920
Subtotal, Operating Costs	$ 93,690	$126,540	$167,920	$215,580
Amortization				
Building	$ 12,720	$ 19,690	$ 32,250	$ 39,200
Scale	1,080	1,080	1,080	1,080
Front End Loader	2,150	2,150	4,090	3,090
Mill(s) and Conveyors	12,400	24,800	37,200	49,600
Stationary Compactor(s)	1,930	1,930	3,860	3,860
Trailers	3,960	5,940	7,960	9,940
Tractor(s)	1,280	1,280	2,560	3,840
Subtotal, Amortization	$ 35,520	$ 56,870	$ 88,000	$110,610
Total Annual Cost	$129,210	$183,410	$255,920	$326,190

TABLE N-27

Annual Costs for One Through Four Mills - Two Shifts

	Number of Mills			
	1	2	3	4
Labor	$102,080	$126,910	$164,630	$197,950
Mill Maintenance	18,160	35,150	53,040	70,850
Power - Mills, Conveyors, and Compactors	8,060	14,110	20,930	26,980
Lighting	2,000	3,460	5,610	6,910
Gas (Heat)	2,980	4,900	7,720	9,520
Water	100	200	290	390
Tractor and Trailer Operation and Maintenance	780	1,550	2,320	3,100
Front End Loader Operation and Maintenance	10,410	12,490	14,580	14,580
Compactor Maintenance	1,440	2,880	4,320	5,760
Subtotal Operating Costs	$146,010	$201,650	$273,440	$336,040
Amortization				
Building	$ 15,330	$ 26,130	$ 41,640	$ 43,980
Scale	1,080	1,080	1,080	1,080
Front End Loader	2,150	2,150	3,090	3,090
Mill(s) and Conveyors	12,400	24,800	37,200	49,600
Compactor(s)	1,930	1,930	3,860	3,860
Trailers	3,960	5,940	7,960	9,940
Tractor(s)	1,280	1,280	2,560	3,840
Subtotal Amortization	$ 38,130	$ 63,310	$ 97,390	$115,390
Total Annual Cost	$184,140	$264,960	$370,830	$451,430

Landfilling Cost Projections

Landfill cost projections will be based on the tonnages processed by each combination of mills and shifts discussed in the previous section. Costs will include labor for compaction, machine operation and maintenance, and equipment amortization. Land costs are excluded. No charges are projected for cover material since no daily cover is used when landfilling milled refuse at Madison.

Labor and Equipment Requirements and Costs:

Projections based on data obtained at Madison reveal that one operator utilizing a steel wheeled compactor can efficiently handle 300 to 360 tons of milled refuse per day. Based on this projection and the assumption that landfills adjacent to the projected plant operations will be operated only one 8-hour shift per day, the following labor and equipment requirements are made.

TABLE N-28

Daily Landfill Labor and
Equipment Requirements

	Number of Mills			
	1	2	3	4
One Shift				
Tons per day	100	200	300	400
Man Shifts	1	1	1	1
Trash Pak(s)	1	1	1	1
Two Shifts				
Tons per day	200	400	600	800
Man Shifts	1	1	2	2
Trash Pak(s)	1	1	2	2

TABLE N-29

Annual Labor Costs - Landfill Operations

	Employee	Annual* Wage	Number of Mills 1	2	3	4
One Shift	Operator	$13,000	$13,000	$13,000	$13,000	$13,000
	Site Control	11,300	5,650	5,650	11,300	11,300
	Supervisor	15,100	3,800	3,800	7,500	7,500
	TOTAL		$22,450	$22,450	$31,800	$31,800
Two Shift	Operator	$13,000	$13,000	$13,000	$26,000	$26,000
	Site Control	11,300	5,650	11,300	11,300	11,300
	Supervisor	15,100	3,800	7,500	15,100	15,100
	TOTAL		$22,450	$31,800	$52,400	$52,400

*Includes 30% fringe benefits excluding overtime.

To compute equipment operating and maintenance costs it is assumed that the landfill compactor will operate a minimum of 2 hours per 8 hour day and a maximum of 6 hours per 8 hour day at the rate of spreading and compacting 45 to 65 tons of milled refuse per hour. Operation and maintenance for landfill equipment are charged at the rate of $6.25/hour of operation. Compactor amortization is charged at the rate of $5,960 per year for an initial investment of $45,000 and an 8-year equipment life.

TABLE N-30

Annual Operating and Maintenance Costs - Landfill Equipment

	Number of Mills 1	2	3	4
One Shift				
Hours	990	1,225	1,470	1,715
Compactor Cost	$6,130	$ 7,660	$ 9,190	$10,720
Misc. Equipment Cost	610	770	920	1,070
Total Cost	$6,740	$ 8,430	$10,110	$11,790
Two Shifts				
Hours	1,225	1,715	2,940	3,430
Compactor Cost	$7,660	$10,720	$18,380	$21,440
Misc. Equipment Cost	770	1,070	1,840	2,140
Total Cost	$8,430	$11,790	$20,220	$23,580

Total Annual Projected Landfilling Costs:

TABLE N-31

Annual Projected Landfilling Costs

Landfill	Number of Mills 1	2	3	4
One Shift				
Labor	$22,450	$22,450	$31,800	$31,800
Compaction Equipment - Operation and Maintenance	6,740	8,430	10,110	11,790
Subtotal Operating Costs	$29,190	$30,880	$41,910	$43,590
Depreciation - Compaction Equipment	$ 5,960	$ 5,960	$11,920	$11,920
Total Operating Costs	$35,150	$36,840	$53,830	$55,510
Two Shifts				
Labor	$22,450	$31,800	$52,400	$52,400
Compaction Equipment - Operation and Maintenance	8,430	11,790	20,220	23,580
Subtotal Operating Costs	$30,880	$43,590	$72,620	$75,980
Depreciation - Compaction Equipment	5,960	5,960	11,920	11,920
Total Operating Costs	$36,840	$49,550	$84,540	$87,900

Summary of Annual Milling and Landfilling Costs

TABLE N-32

Annual Cost of Milling, Milled Refuse Transfer System and Landfilling - One Shift

	Number of Mills			
	1	2	3	4
Annual Tonnage	24,500	49,000	73,500	98,000
Reduction Plant & Transfer				
Operating Costs	$ 93,690	$126,540	$167,920	$215,580
Amortization	35,520	56,870	88,000	110,610
Total Reduction Plant	$129,210	$183,410	$255,920	$326,190
Cost Per Ton*	$5.27	$3.74	$3.48	$3.33
Millfill				
Operation Costs	$ 29,190	$ 30,880	$ 41,910	$ 43,590
Amortization	5,960	5,960	11,920	11,920
Total Landfill	$ 35,150	$ 36,840	$ 53,830	$ 55,510
Cost Per Ton**	$1.43	$0.75	$0.73	$0.57
TOTAL ALL OPERATIONS	$164,360	$220,250	$309,750	$381,700
COST PER TON	$6.70	$4.49	$4.21	$3.90

*Cost includes amortization, labor, operating, and milled refuse haul to landfill less than one-half mile round-trip distance. Land cost excluded.

**Millfill cost includes labor and equipment costs with amortization. Land cost and site preparation costs are excluded.

TABLE N-33

Annual Cost of Milling, Milled Refuse Transfer System and Landfilling - Two Shifts

	Number of Mills			
	1	2	3	4
Annual Tonnage	49,000	98,000	147,000	196,000
Reduction Plant & Transfer				
Operating Costs	$146,010	$201,650	$273,440	$336,040
Amortization	38,130	63,310	97,390	115,390
Total Reduction Plant	$184,140	$264,960	$370,830	$451,430
Cost Per Ton*	$3.75	$2.70	$2.52	$2.30
Millfill				
Operating Costs	$ 30,880	$ 43,640	$ 72,620	$ 75,980
Amortization	5,960	5,960	11,920	11,920
Total Landfill	$ 36,840	$ 49,600	$ 84,540	$ 87,900
Cost Per Ton	$0.75	$0.50	$0.57	$0.45
TOTAL ALL OPERATIONS	$220,980	$314,560	$455,370	$539,330
COST PER TON**	$4.50	$3.20	$3.09	$2.75

*Cost includes amortization, labor, operating, and milled refuse haul to landfill less than one-half mile round-trip distance. Land cost excluded.

**Millfill cost includes labor and equipment costs with amortization. Land cost and site preparation costs are excluded.

O - Composition of Madison's Solid Waste

This is a report on work done by the Bureau of Solid Waste Management to determine the composition of Madison's solid wastes.

COMPOSITION OF SOLID WASTES: MADISON, WISCONSIN (TSR/01.15/9)

During the week of November 4, 1968, solid waste influent to the Madison, Wisconsin, Refuse Reduction Plant was sampled and categorized. This study was conducted by personnel of the Solid Wastes Program as a training exercise for new engineers and to provide needed data to the demonstration project. The results of the separation were submitted to the City of Madison.

Residential solid wastes were sampled on November 5, 6 and 7, 1968. Incoming packer trucks were directed to the sampling area, and the driver was instructed to lift the tailgate until enough wastes had been dumped. Previous experience had shown that 200-lb. samples would be sufficient if more than eight separations were made. The wastes dumped from the trucks would then be randomly subdivided until the resulting sample was judged to be 200 lbs. or more. Four separations were made on November 5 and on November 6. Two separations were made on November 7. Usual practice was to take each sample from a different truck.

After the samples were selected, they were hand sorted into the following components:

Food Wastes
Garden Wastes
Paper Products
Plastics, Rubber and Leather
Textiles
Wood
Metals
Glass and Ceramics
Rocks, Dirt, Ashes, etc.

The percentage of each component was then determined on as as-received or wet basis.

Moisture content determinations were made on half of the samples, the first and fourth samples the first two days and the first sample on the third day. This was done by combining one percent of the weight of the food wastes, paper products, and garden wastes components for a particular sample. The moisture contents determined for these portions were then adjusted to reflect the moisture contents of the total samples.

The minimum, maximum, and average percentages of each component, by weight, are given below.

TABLE 0-1

Range of Compositions of Madison's Solid Wastes (Wet Basis) by Federal Solid Wastes Program (Nov. 1968)

	Minimum (%)	Maximum (%)	Average (%)
Food Wastes	4.4	28.9	15.3
Garden Wastes	0.0	31.1	13.8
Paper Products	35.1	53.2	42.4
Plastics, Rubber, Leather	0.3	3.7	1.8
Textiles	0.1	7.8	1.6
Wood	0.0	2.6	1.1
Metals	5.0	14.5	6.7
Glass and Ceramics	4.4	17.6	10.1
Rocks, Dirt, Ashes, etc.	0.6	17.6	7.2

Note: The moisture content varied from 30 to 48 percent, with an average of 37 percent.

F - List of European Sites Visited and Persons Interviewed

SITES

Location	Mill Used At Facility
UNITED KINGDOM	
1. Bishopbriggs	British Jeffery Diamond
2. Bathgate	Volund - John Thompson
3. Brackley	Gondard
4. Chesterfield	Buhler
5. Cringle Dock - Greater London Council	British Jeffery Diamond
6. East Grinstead	Tollemache
7. Horsham	Tollemache
8. Leamington Spa	Gondard
9. Scunthorpe	British Jeffery Diamond
10. Woking	Vicker Seerdrum
11. Worthing	British Jeffery Diamond
FRANCE	
1. Elbeuf	Gondard
2. Louvier	Gondard
3. Meaux	Gondard
4. St. Etienne de Vouvray	Gondard
5. St. Quentin	Gondard
SWITZERLAND	
1. Aarau	Landfill
2. Biel	Buhler
3. Flims	Buhler
GERMANY	
1. Russelsheim	Gondard
2. Hockheim	Landfill
3. Wiesbaden	Gondard

INTERVIEWS

	Name	Affiliation
1.	E. R. Green	Dept. of the Environment, United Kingdom
2.	D. Parkinson	British Jeffery Diamond, Ltd.
3.	Serge Pollet	Rural des Eaux et Forets
4.	Guy F. Robinson	Tollemache Composting Systems, Ltd.
5.	Jacques Sigwalt	Gondard
6.	Dietegen Stickelberger	World Health Organization
7.	J. Sumner	Dept. of the Environment, United Kingdom

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